GRAYS HARBOR RESPONSE CAPACITY ANALYSIS

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EXECUTIVE SUMMARY

The Washington Department of Ecology contracted Nuka Research and Planning Group, LLC to conduct an oil spill response capacity analysis for Grays Harbor, Washington. The purpose of the study is to better understand response capacity for the area if all resources in current planning were deployed for a major oil spill response there. The study does not consider all aspects of a response, but instead applies the publicly available Response Options Calculator (ROC) to model maximum potential response capacity for a base case spill. Additional scenarios are then modeled in ROC to answer a series of research questions. The Grays Harbor Safety Committee and other stakeholders provided input to the development of the base case and research questions through workshops held in April and December 2018.

ROC is a simplified model of an oil spill response. It first models the spread and weathering of a hypothetical oil spill based on the oil type, winds, and water temperature. Then it applies a set of information about a recovery system (the combination of vessels, skimmer, boom, primary storage used together to recover oil) to determine the maximum potential oil recovery of system when applied to that oil slick. ROC incorporates the time a system arrives on scene, skimming capacity, type of skimmer, speed of advance, swath width captured by the boom, throughput and recovery efficiencies, decanting (when used), and primary storage volume. Calculations are then made to determine how long the system would need to stop skimming in order to transit to and offload at offload secondary storage, when full, before skimming can begin again. Each scenario in this analysis considers the simultaneous use of multiple recovery systems and presents a maximum potential recovery for the combined response forces from Washington and Oregon that may respond to a major spill in Grays Harbor.

While ROC provides a more complex way of modeling oil spill recovery than just a derated pump rate alone (as used in regulations), it does not capture all the complexity of the real world. These other important factors include, but are not limited to, currents, waves or fog, responder availability and training, equipment malfunctions, or other issues that may slow down a response or otherwise reduce oil recovery. In Grays Harbor, the tidal fluctuations and associated currents would have a very strong impact on the outcome of any actual spill and will change the recovery tactics used or render on-water recovery impossible in some places or at some tide stages. It is also a very confined waterway and may be difficult or at times impossible for all the systems analyzed to operate simultaneously. Even as we acknowledge the limitations of ROC, it can still provide a valuable piece of information to inform response planning along with an understanding of the operating environment and the conditions responders may encounter.

In this study, the base case is a spill of 1.5 million gallons of marine diesel at Terminal 1 in the Port of Grays Harbor. All Marine Spill Response Corporation and National Response Corporation systems assigned to a potential Grays Harbor response are used. The recovery system information and time of arrival was obtained from these organizations based on information provided to the Department of Ecology. Where additional inputs were needed, both organizations helpfully vetted the inputs related to their systems prior to the analysis.

RESEARCH QUESTIONS

Base Case

1. What is the maximum potential oil recovery for a 1.5 million-gallon diesel spill at Terminal 1?

Spill Context

2. How does changing the location of the spill within Grays Harbor affect maximum potential oil recovery?

3. How does changing the time of day of the spill affect maximum potential oil recovery?

4. How does changing the wind speed affect maximum potential oil recovery?

5. How does changing the amount of daylight affect maximum potential oil recovery?

6. How does changing the water temperature affect maximum potential oil recovery?

7. How do delays in response mobilization or deployment affect maximum potential oil recovery?

8. How does changing the oil type spilled affect maximum potential oil recovery?

9. How does changing the oil type and spill size affect maximum potential oil recovery?

Response Resources

10. How does adding a dedicated response barge to the area affect maximum potential oil recovery?

11. How does changing the recovery systems used affect maximum potential oil recovery?

The base case spill resulted in a maximum potential recovery of 82% during the 48-hour response period based on the ROC model and inputs used. Compared to this, response at different locations resulted in a decrease in potential recovery (see Figure ES-1). This was primarily due to having farther to travel to offload primary storage (and thus more downtime in skimming). Several aspects of the spill context had minimal impact on the results: whether the spill occurred at 7am or noon and whether it occurred during Winter Solstice or Summer Solstice (with the shortest and longest periods of daylight respectively) had minimal impact. Warmer water meant a slightly reduced potential recovery.

Increasing the wind speed or significantly delaying the response (regardless of reason) had a much greater impact. Winds of 18 knots, which can occur throughout the year, resulted in more than 30% less potential recovery than the base case. A delay of 24 hours would mean almost 50% less potential recovery than the base case.

Because of the way it weathers, spilling IFO-380, a common vessel fuel, may result in a slight increase in potential recovery at each of the three locations analyzed. This is due to the fact that this oil will emulsify slightly which thickens the slick but not to the point that it is rendered unrecoverable at least based on the ROC weathering model.

The response was modeled with the addition of a hypothetical response barge to the region so that secondary storage would be immediately available at locations throughout Grays Harbor. The availability of secondary storage and the time it takes to travel to and from that storage are important factors in a response: if primary storage fills a system must stop recovery until it can offload collected fluids. In this case, however, there was not a significant gain made as compared to just offloading primary storage at the terminal.

The analysis shows that response capacity in Grays Harbor is significant. The success of any response – especially in a tide-dominated environment such as Grays Harbor – will depend on the ability to deploy resources as quickly as possible before the oil spreads or moves with the currents. The training of responders and vessel operators (including vessels of opportunity) in deploying on-water recovery tactics to be as effective as possible in high currents will also be critical. From this analysis, it does not appear that adding a barge to the region would provide a meaningful improvement to the system.

Finally, this analysis used diesel as for the base case scenario because sufficient information about biodiesel properties was not available despite the Department of Ecology's attempts to obtain the necessary laboratory results. Better information about biodiesel would inform any future analysis of response capacity for the region.

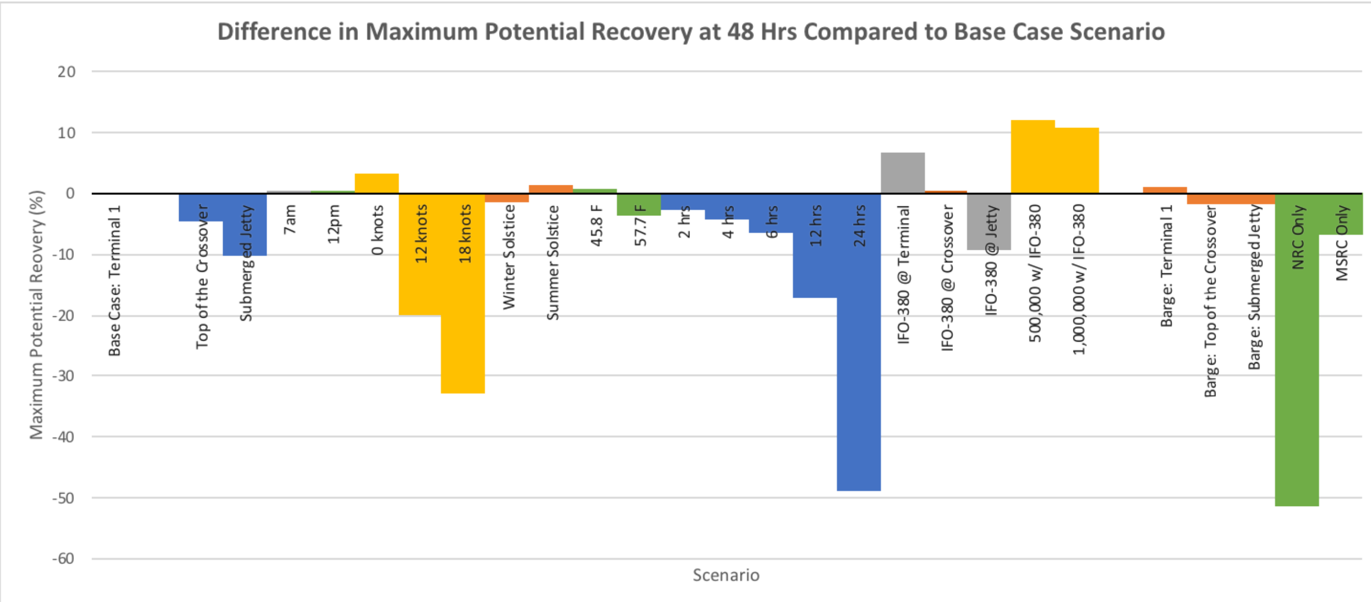

Figure ES-1. Maximum potential recovery at 48 hours for spill scenarios modeled in ROC. Scenarios are compared to the base case.

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1 INTRODUCTION

The Washington Department of Ecology contracted Nuka Research and Planning Group, LLC (Nuka Research) to conduct an oil spill response capacity analysis for Grays Harbor. The purpose of the study is to better understand response capacity for the area based if all resources in current planning were deployed for a major oil spill response there.

1.1 SCOPE AND APPROACH

This analysis estimates the maximum potential on-water oil recovery through a series of modeled scenarios that compare the effect of different factors on recovery under idealized conditions.[1]

Potential on-water recovery capacity is used as a proxy for overall spill response capacity. The protection of shorelines, cleanup of oiled shorelines, and wildlife response are also critical aspects of a spill response that are outside the scope of this study. In the Grays Harbor area, it is assumed that shoreline oiling would be inevitable and likely heavy, due to the significant tides.

This study does *not* evaluate the likelihood that an oil spill may occur, nor does it consider the consequences of an oil spill. This study is also not a policy or compliance analysis. While information from oil spill contingency planning and planning requirements in Washington was used to inform the analysis, this study is not intended to evaluate the appropriateness of any specific policy or regulation, nor does it evaluate whether regulated parties comply with state or federal requirements.

1.2 STAKEHOLDER INPUT TO STUDY

The project was initially formulated and discussed with the Grays Harbor Safety Committee in an April 2018 workshop convened by the Washington Department of Ecology (Department). Following this, Nuka Research was contracted to conduct the analysis. In a December 2018 workshop, the Department and Nuka Research met with

[1] This analysis is conducted using inputs based on the Grays Harbor context to the extent possible in the model. Research questions and inputs were developed with input from the Grays Harbor Safety Committee and other stakeholders and differ from inputs used in a 2015 study of response capacity in the San Juan Islands. Results from this study are compared to that other study in Appendix A.

Harbor Safety Committee members again to review the methodology and gain input on research questions and response scenarios. The three scenario locations, general research questions, and baseline scenario inputs were agreed to at this time. A final meeting was held in June 2019 to present the results and take questions and comments. The report was then distributed to Committee members and other stakeholders for comments on the draft prior to completion at the end of June.

Nuka Research and the Department of Ecology appreciate the time and input of those who participated in the process. We note that their participation does not represent an endorsement of the approach or the results, but that both are no doubt improved by the input received.

2 BACKGROUND

Grays Harbor is located on Washington's central coast. Figure 2-1 shows the area as depicted in a National Oceanic and Atmospheric Association (NOAA) chart (18502), which portrays the extensive tide flats within the harbor area.

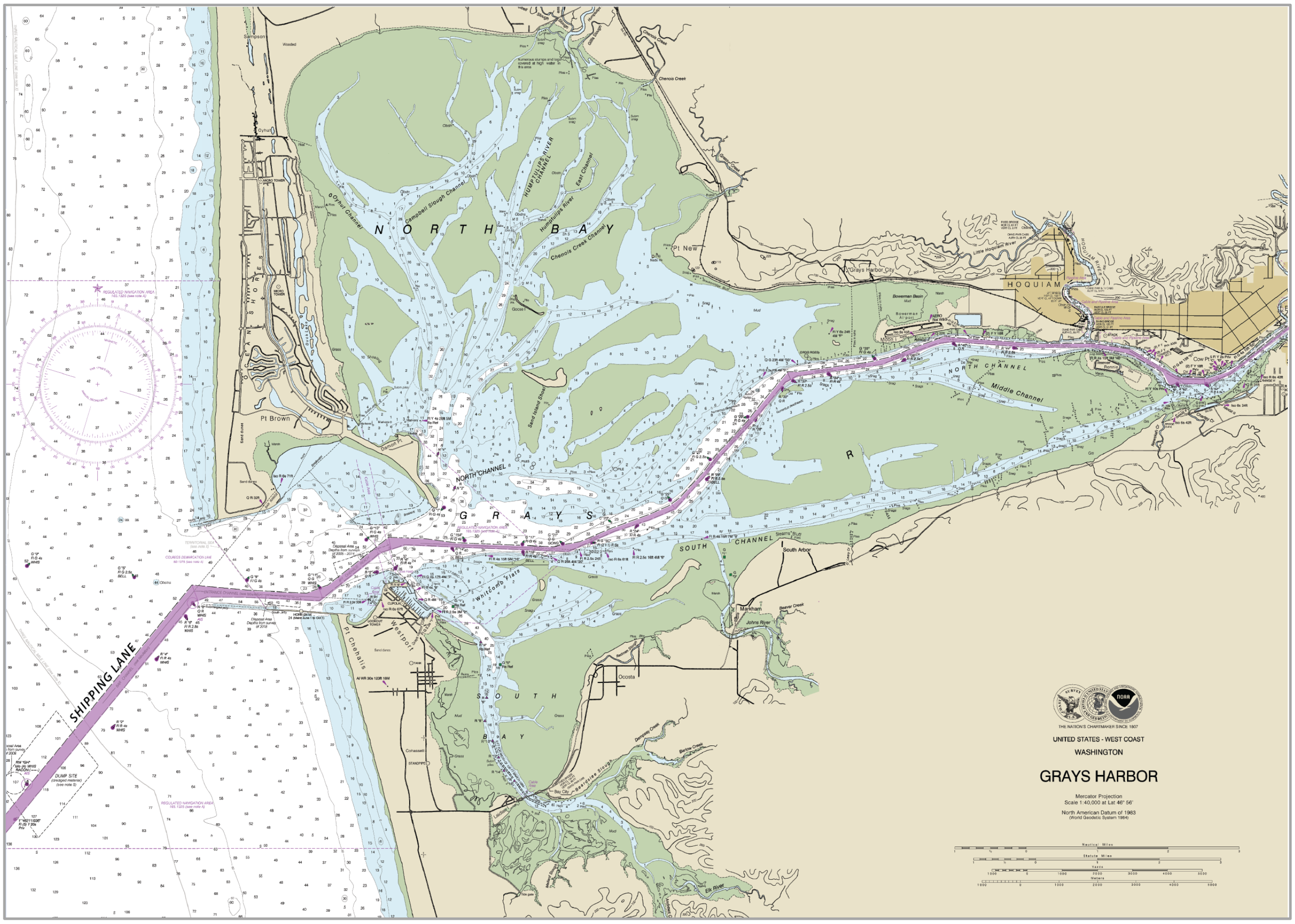

Figure 2-1. Grays Harbor, including shipping lane as depicted on NOAA chart

2.1 OPERATING ENVIRONMENT

Excerpts from the 2018 Grays Harbor Vessel Traffic Risk Assessment (GHVTRA) (inset 1) describe the operating environment and vessel traffic there. This is a confined waterway and highly tide-dependent environment.

In the navigation channel itself, current speed typically does not surpass 3 knots, but it can be more extreme at the entrance to the harbor, with currents measured up to 5 knots. Net current is headed seaward, out of the harbor. Average incoming current is about 1.9 knots on the flood tide and average outgoing current is about 2.8 knots on the ebb tide. Currents by the interior shores of the harbor are affected by the rivers that feed into it, and typically increase in the winter when the rivers have stronger flow due to storms. The harbor itself has an average tidal rise of 9 feet. At high tide, water covers about 94 square miles of the harbor, while at low tide only about 38 square miles is covered, with the rest being exposed mudflats and sand bars. (Department of Ecology, 2016). Figure 2-2 depicts current fluctuations for March 21-22, 2019 at Grays Harbor Entrance. This is provided as one example of currents at the same season as the base case spill scenario used in this study. Currents will vary by day, season, and location.

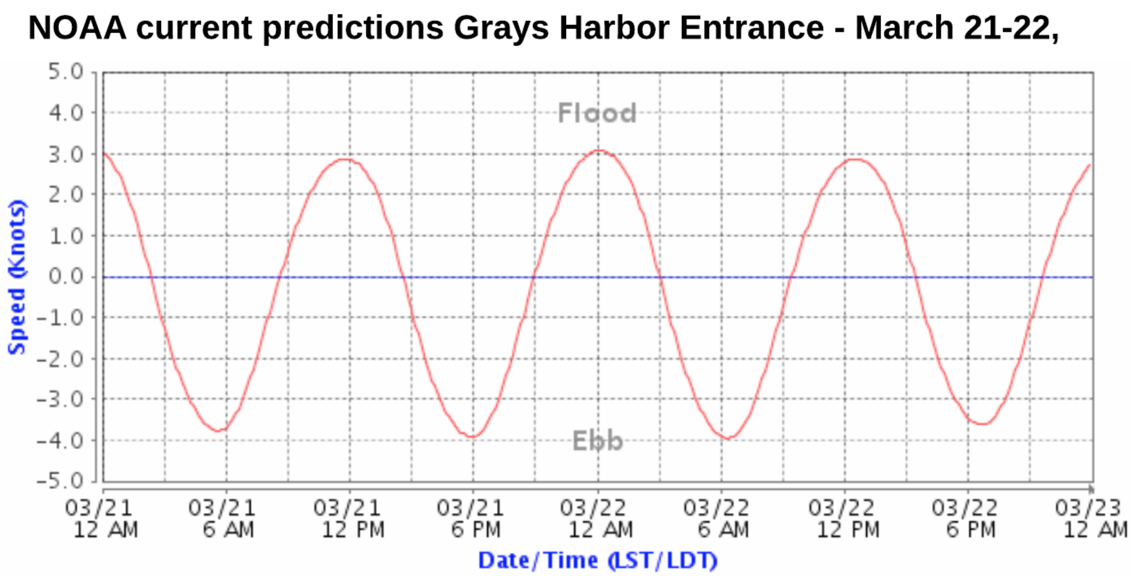

Figure 2-2. Currents predicted by NOAA for Grays Harbor entrance on March 21-22, 2019. Based on: https://tidesandcurrents.noaa.gov/noaacurrents/Stations?g=698

The strong currents and tidal fluctuations combined that mounting a significant response in Grays Harbor will be difficult. Oil is likely to move fairly rapidly in or out of the Harbor or strand on shore (possibly to refloat when the tide comes back in). Strong currents can make on-water recovery difficult or impossible. There may be bottlenecks deploying response resources if the staging area is not large enough and moving dozens of vessels around recovering oil – especially at night – will be challenging and may be impossible at low tide.

As is the case anywhere, on-water recovery may also be impeded by wind, waves, or poor visibility. Fog can make vessel operations unsafe. If aircraft are used to track the oil, both fog and cloud ceiling are limiting.

Description of Grays Harbor
Excerpts from Grays Harbor Vessel Traffic Risk Assessment (2018)

The entrance to Grays Harbor is about one mile wide, but shoals extending from the north and the south of the entrance reduce the navigable channel to a width of less than half a mile. The bay comprising Grays Harbor extends east for approximately 15 miles to the mouth of the Chehalis River. The bay is filled with shoals and flats, some of which are bare at low water (NOAA, 2017).

As with other inlets on the California, Oregon, and Washington coasts, there is a bar at the entrance to Grays Harbor. These bars form where rivers and streams empty into the Pacific Ocean, causing the river runoff to slow and deposit sediment.

The tidal current at the bar can reach considerable velocity, especially when an ebb tide is reinforced by river runoff. Dangerous conditions can develop when a swift ebb current meets swells from the Pacific at the relatively shallow bar. The change in water depth and opposing forces of current, swell, and sometimes wind, can cause breaking waves and rough seas. Conditions can change rapidly and without warning. Additionally, the area where the effects of the bar are observed changes with conditions. The true bar at Grays Harbor is considered to be from midway between Buoys 2 and 4 to the south, extending northeast to Buoy 8, see Figure 2 (Grays Harbor Safety Committee, 2014).

The average current velocity at the bar is about 1.9 knots on a flood tide and 2.8 knots on an ebb tide, but velocities can reach 5 knots. Currents in the vicinity of the bar are reported to be erratic. The U.S. Coast Guard Captain of the Port may restrict passage or close the bar to navigation based on weather conditions. The Grays Harbor Pilots may also suspend service to commercial vessels (Grays Harbor Safety Committee, 2014).

The Grays Harbor navigation channel is maintained by the U.S. Army Corps of Engineers. Twin jetties to the north and south secure the mouth of the harbor. The deep draft channel is 22 miles long from the Pacific Ocean to the city of Aberdeen. The channel is 1,000 feet wide over the Grays Harbor Bar and 350 feet wide eastward of the bar. (U.S. Army Corps of Engineers, 2018).

References:

Grays Harbor Safety Committee. (2014). *Grays Harbor Safety Plan.* Revised October 2016. Retrieved from Port of Grays Harbor website: http://www.portofgraysharbor.com/harborsafety/downloads/archive/Harbor-Safety-Plan_Grays-Harbor.pdf

National Oceanic and Atmospheric Administration. (2017). *Coast Pilot 7 Pacific Coast: California, Oregon, Washington, Hawaii and Pacific Islands 2017 (49th edition).* Retrieved from NOAA Office of Coast Survey website: https://www.nauticalcharts.noaa.gov/publications/coastpilot/index.html

U.S. Army Corps of Engineers. (2018). Grays Harbor navigation. Website. Retrieved on July 5, 2018 from USACE website: http://www.nws.usace.army.mil/Missions/Civil-Works/Navigation/Navigation-Projects/Grays-Harbor/

2.2 VESSEL TRAFFIC

In 2017, the Department of Ecology documented 12 tanker transits and 97 cargo or passenger transits through Grays Harbor. (There were no tank barge or Articulated Tug and Barge movements) (Department of Ecology, 2018). The number of tanker transits has fluctuated in recent years. The number of vessels cargo and passenger transits also fluctuates, but has increased (Department of Ecology, 2002-2018). See Figure 2-3.

The only oil[2] moved as cargo is non-petroleum biodiesel or canola oil from the Renewable Energy Group (REG) bio-refinery (Renewable Energy Group Inc., 2018) located at Terminal 1 of the Port of Grays Harbor. There is also a methanol and magnesium oxide terminal, as well as shipments of logs and other non-liquid cargoes.

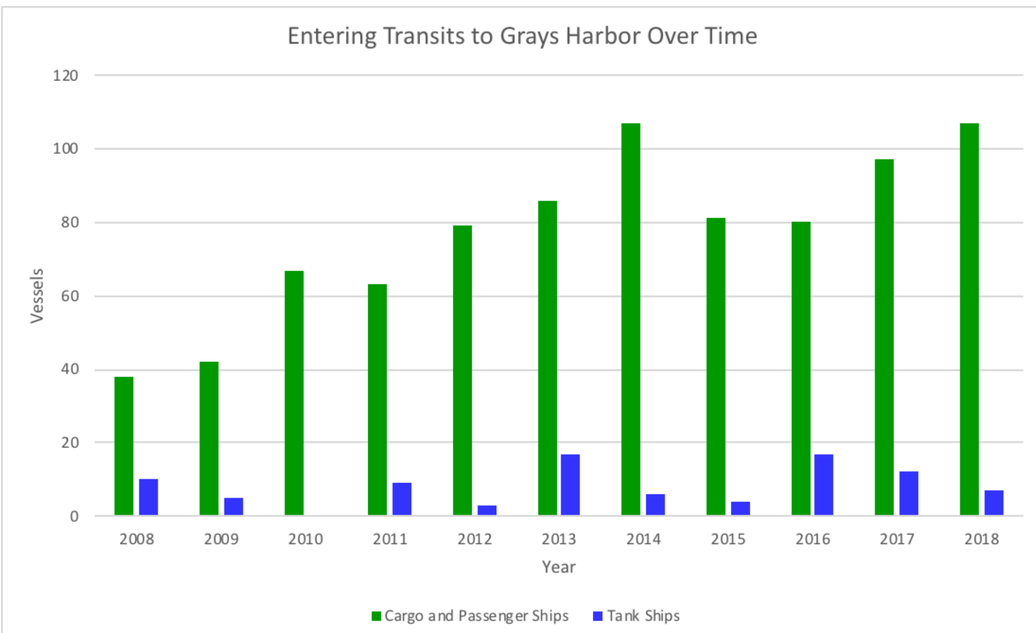

Figure 2-3. Transits of Cargo and Passenger vessels and Tankers in Grays Harbor based on Vessel Entries and Transit data from the Department of Ecology (2008-2018)

2.3 OIL SPILL FATE AND BEHAVIOR

Oil spilled into the marine environment will immediately begin to move with the tides, current, and wind. Oil will also begin to undergo physical and chemical changes through a process known as weathering. Oil movement and weathering will depend on the type

[2] "Oil" under Washington law includes "biological oils and blends" (RCW 88.46.010).

of oil spilled and the characteristics of the marine environment at the time. Spilled oil will:

- Spread horizontally across the water's surface as the slick thins or is transported by tidal currents or winds,
- Evaporate,
- Disperse within the water column; and
- Submerge either partially or fully (ITOPF, 2012).

Physical and biological processes involved in oil weathering include spreading, evaporation, dispersion, dissolution, emulsification, photo-oxidation, sedimentation, and biodegradation as shown in Figure 2-4.

Oil transport and weathering vary depending on the type of oil; mixing energy from current, waves, or winds; air and water temperature; and salinity (ITOPF, 2012).

Lighter, refined petroleum-based products such as gasoline, kerosene, or diesel tend to spread rapidly into silver or rainbow sheens, evaporate quickly, and leave minimal residue, if any (EPA, 2014). By contrast, heavier crude oils are more likely to emulsify and become viscous, especially if they contain asphaltenes and resins, eventually coating shorelines and sinking (ITOPF, 2012).

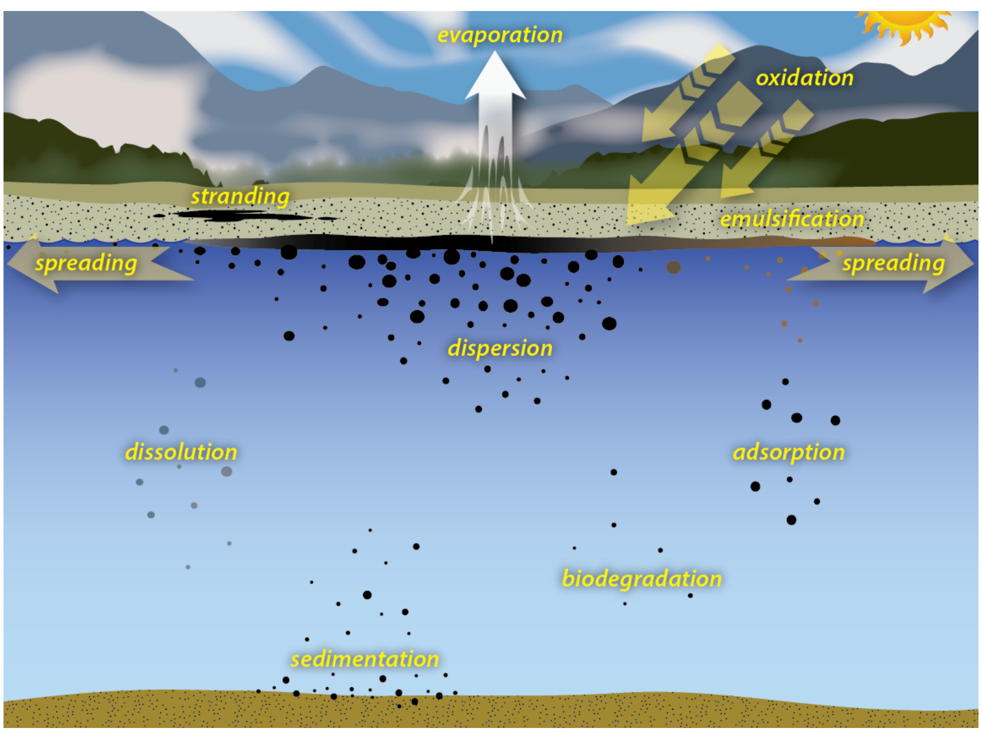

Figure 2-4. Oil weathering processes (NOAA, 2015)

2.4 OIL SPILL RESPONSE

There are different approaches to containing, cleaning up, and treating oil spills. This study focuses on the mechanical recovery of oil that is floating on the water, sometimes referred to as free-oil recovery. Mechanical recovery of free-floating oil is considered the preferred method to remove oil from the marine environment. This approach uses oil recovery systems – primarily containment boom, oil skimmers, pumps, hoses, and storage devices – to contain, recover, and store spilled oil. Oil may be contained on the water using different configurations of floating oil boom moved by vessels through the water. There are likewise many different types of skimming devices that recover the oil from the water's surface (Potter, 2012). Oil and water (or other debris) that have been skimmed from the surface are held in primary storage tanks. Once these tanks are full, the recovered fluids must be transferred to secondary storage tanks and the primary storage systems returned to service. These recovered liquids must eventually be transported to a shore-based facility for long-term storage, treatment, and disposal. Adequate storage is critical to on-water mechanical recovery operations. If storage runs out, recovery must cease. Decanting of the excess free water from the fluids recovered is a technique used during large spills to reduce the amount of storage required.

Figure 2-5 shows a generalized example of the process from containment to storage. Not pictured, but equally important, are the parts of the process that include finding or tracking the slick and managing the collected oily waste in accordance with state and federal law.

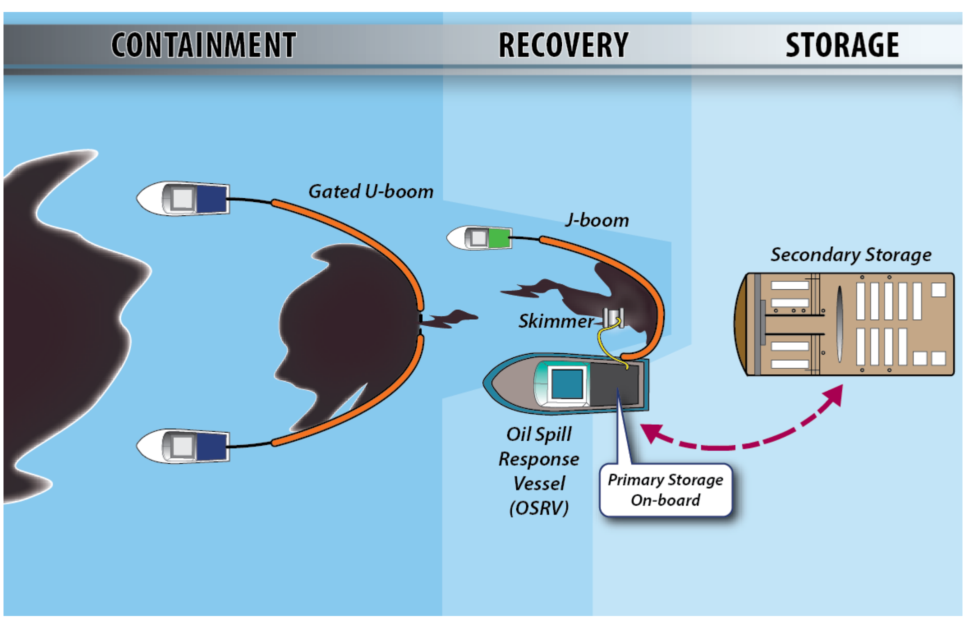

Figure 1-5. Generalized on-water mechanical recovery from containment to storage

Mechanical oil spill response relies on being able to access the oil on the surface of the water. In order for free-oil recovery tactics to be effective, the oil must be floating. Weathering, as described earlier, may also increase the oil viscosity (thickness) of the oil or emulsification (mixing with water). Both of these processes can also impact mechanical recovery. Oil that reaches shore may become stranded there and is thus no longer available for on-water mechanical recovery tactics. Oil that reaches the shoreline may re-mobilize or incorporate shoreline sediments. Re-mobilized oil is more likely to submerge or sink. Oiled shorelines may still be cleaned up, but adverse ecological impacts will occur as a result of the oiling, and the clean-up process can be very lengthy and labor-intense. (Shoreline protection and cleanup were not modeled as part of this study.)

The natural movement and weathering of an oil spill starts immediately after the spill and necessitates immediate response operations if any significant amount of oil is to be efficiently recovered from the surface of the water. There is general consensus among spill response professionals that the best window-of-opportunity for mechanical recovery of oil spills that remain floating is within the first 72 hours after the spill occurs (Dale et al., 2011; Nordvik, 1995). In some circumstances oil may be unrecoverable after just a few hours if it submerges, strands on shore, emulsifies significantly, or is otherwise spread rapidly due to strong wind or currents.

2.5 OIL SPILL RESPONSE PLANNING IN WASHINGTON

All tankers and other vessels greater than 300 gross tons transiting Grays Harbor are required to meet both U.S. federal and Washington State oil spill contingency planning requirements. State-approved contingency plans must demonstrate that plan holders have available sufficient equipment to meet regional response planning standards. Planning standards refer both to equipment (boom, skimmers, and storage) and also the time it takes to get it there. Plans may draw on resources from around the state or beyond, but they are region-specific in terms of the assumptions regarding transit times and capacity needed (Department of Ecology, 2019).

3 METHODOLOGY

After ensuring that everyone is safe, the first priorities in an oil spill response are to control the spill at its source and contain and recover oil that has spilled before it reaches the shore or mixes into the water column.

This study used estimated on-water recovery of free-oil as proxy for oil spill response system capacity. Maximum potential response capacity is expressed as the total amount of oil and the percentage of the oil spilled that could be recovered from a theoretical spill scenario in the marine environment. This information is obtained by inputting information about response resources and other parameters into a model called the Response Options Calculator.

Scenarios were modeled to examine the relative impacts of different factors on the estimated amount of oil that could be recovered from the water's surface. This section describes the study methodology.

3.1 OVERVIEW OF APPROACH

Marine oil spills are complex phenomena shaped by the amount and type of oil spilled, and the environmental conditions at the time of the spill (currents, wind, sea state, temperature, and salinity). Oil spill recovery operations are also complex. Their effectiveness depends on the nature of the spill as noted above, type and capabilities of response equipment, proficiency of the responders, ability to locate and track the oil slick, logistical support to sustain the response, and ability to operate in environmental conditions at the time. In order to estimate potential oil spill recovery, a model can be used to calculate the effects of some of the variables mentioned above. Some simplifications must be made in order to reduce the complexity of the system. Even the most intricate models have inherent inaccuracies and are unable to predict real world outcomes. However, a model such as the one used in this study can be useful to understand the relative effect of variables within a complex oil spill event and to estimate the overall potential of a recovery capacity of a set of response systems.

This study applies the Response Options Calculator (ROC), developed by Genwest Systems, Inc. for the National Oceanic and Atmospheric Administration (NOAA, 2012; Genwest Systems, Inc. 2012) to model how on-water oil spill response forces from Washington and Oregon could be applied to various spill scenarios in Grays Harbor, Washington. The ROC estimates the potential oil recovery capacity based on oil properties, specific (and simplified) oil spill response forces, and specified (and simplified) environmental conditions. It allows for consideration of spill timing, seasonality (hours of daylight), simplified environmental conditions (wind speed, water temperature), oil properties, and deployment logistics to estimate on-water oil recovery (Mattox et al., 2014; Dale et al., 2011). This study builds on previous work that used ROC or derivative models to estimate the response capacity of a given system (Nuka Research 2015, 2013, 2012a, 2012b; Genwest Systems, Inc., 2012).

The ROC combines previously developed NOAA models and adds new algorithms for slick spreading to: (1) model oil weathering based on the inputs used and (2) estimate the amount of oil affected by skimming operations (or in-situ burning or dispersant application) (Dale, 2011).

The analysis follows these steps:

1. Develop research questions (see Section 2.2)
2. Develop parameters for hypothetical response scenarios to answer research questions
3. Define response systems based on response resource inventories and locations, and best professional judgment regarding how response forces may be used
4. Define model inputs
5. Model scenarios
6. Present and interpret results

Considerations for the use of the ROC are discussed in Section 3.2 Research questions are listed in Section 3.3. The base case against which scenarios are compared to answer research questions is described in Section 3.4.

3.2 USE OF THE RESPONSE OPTIONS CALCULATOR

Modeling is necessarily dependent upon a series of assumptions. Assumptions inherent to ROC are described in the ROC Technical Document (Genwest Systems Inc., 2012). General assumptions include:

- Weather and environmental conditions are conducive to safe response operations.

- Oil is accessible to recovery systems (it remains floating on the water's surface and does not submerge or strand on shore).
- All equipment listed in inventories is available and operates without malfunction or failure. In addition, permission must be granted by the appropriate authorities to release the equipment from facilities in Washington where it is relied upon for contingency plan compliance, and from Oregon.
- The response proceeds safely, with no disruptions.
- All necessary personnel are adequately trained, proficient in their required skills, and available in a timely manner.
- Sufficient personnel are available to sustain operations for each on-water recovery system for 24-hours (for systems capable of night operations), and for all daylight hours (for daylight-only systems).
- All necessary logistical support is available and fully functioning.
- Spill tracking and surveillance is effective and responders are successfully directed to the slick.
- Skimming systems operate in oil slicks of the average thickness of the given oil for the age of the spill.

Figure 3-1 shows graphically how the use of optimistic assumptions leads to a best-case outcome. The real-world outcome will be worse: it will be determined by actual conditions and influenced by factors that are not incorporated in the model.

It is not necessary to use a model to know that due to weather or other factors, it may be the case that *no oil* is recovered. As the purpose of the study is to understand the *relative impacts* of different factors or planning decisions on a hypothetical response, the model is most useful when assumptions are generally conducive to at least some oil recovery. While other models or analytical approaches may be used to estimate the likelihood of a spill, the potential for different spill volumes, the consequences of a spill, or the percentage of the time when no response is possible due to environmental conditions, these are outside the scope of this study.

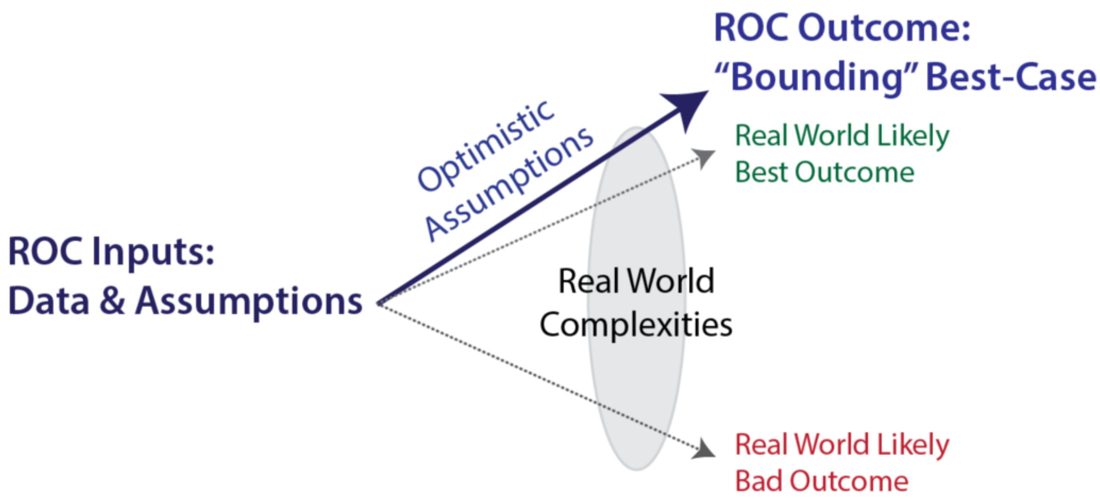

Figure 2-1. Conceptual diagram depicting the influence of optimistic assumptions on ROC outputs (based on Mattox et al., 2014)

3.3 RESEARCH QUESTIONS

This study models spill scenarios to answer the research questions listed below, which were developed with input from the Washington Department of Ecology and Grays Harbor Safety Committee. The research questions fall into three categories: (1) spill context and (2) response resources used. Section 4 describes the scenarios in more detail. The scenario used for Research Question #1 serves as the base case against which scenarios used to answer the subsequent research questions are compared. Questions #2-7 relate to the spill context (location, product spilled, volume of spill, wind speed, amount of daylight, water temperature). Question #8 refers to delays in response mobilization or deployment. This could occur because of errors or planning failures, or because conditions preclude prompt deployment of recovery operations. Questions #9-10 address response resources (which are used and the availability of hypothetical dedicated response barge).

Base Case

1. What is the maximum potential oil recovery for a 1.5 million-gallon diesel spill at Terminal 1?

Spill Context

2. How does changing the location of the spill within Grays Harbor affect maximum potential oil recovery?

3. How does changing the time of day of the spill affect maximum potential oil recovery?

4. How does changing the wind speed affect maximum potential oil recovery?

5. How does changing the amount of daylight affect maximum potential oil recovery?

6. How does changing the water temperature affect maximum potential oil recovery?

7. How do delays in response mobilization or deployment affect maximum potential oil recovery?

8. How does changing the oil type spilled affect maximum potential oil recovery?

9. How does changing the oil type *and* spill size affect maximum potential oil recovery?

Response Resources

10. How does adding a dedicated response barge to the area affect maximum potential oil recovery?

11. How does changing the recovery systems used affect maximum potential oil recovery?

3.4 VARIABLES AND RESPONSE SCENARIOS

The following variables were modified to answer the research questions. The inputs for each scenario and associated research question are shown in Table 3-1. These are discussed further in the explanation of the answers to the research questions in Section 3.

- Location within Grays Harbor
- Date (applicable to hours of daylight)
- Spill context (oil type, volume, time of day of the spill)
- Wind speed
- Water temperature
- Which response systems are used (NRC, MSRC)
- Response delays (regardless of cause)

Table 3-1. Research questions and scenarios used for ROC analysis

Location	Time of Day	Oil Type	Spill Volume (gall)	Day /Dark (season)	Wind Speed (knots)	Water Temp. (ºF)	Response Forces	Delay (Hours)	Transit Times w/in GH
BASE CASE									
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
How does changing the **location** of the spill within Grays Harbor affect maximum potential oil recovery?									
Top of the Crossover (buoy 32-29)	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Westport	48	MSRC and NRC	0	1
Submerged Jetty (response inside Harbor)	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Westport	48	MSRC and NRC	0	3
How does changing the **time of day** of the spill affect maximum potential oil recovery?									
Terminal 1	First light (7 AM)	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
Terminal 1	Noon	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
How does changing the **wind speed** affect maximum potential oil recovery?									
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	0 (calm)	48	MSRC and NRC	0	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	12	48	MSRC and NRC	0	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	18	48	MSRC and NRC	0	0.5
How does changing the **amount of daylight** affect maximum potential oil recovery?									
Terminal 1	Midnight	Diesel	1.5 million	Winter Solstice	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5

Location	Time of Day	Oil Type	Spill Volume (gall)	Day /Dark (season)	Wind Speed (knots)	Water Temp. (ºF)	Response Forces	Delay (Hours)	Transit Times w/in GH
Terminal 1	Midnight	Diesel	1.5 million	Summer Solstice	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
How does changing the **water temperature** affect maximum potential oil recovery?									
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	45.8	MSRC and NRC	0	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	57.7	MSRC and NRC	0	0.5
How do **delays in response** mobilization or deployment affect maximum potential oil recovery?									
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	2	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	4	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	6	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	12	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	24	0.5
How does changing the **oil type** spilled affect maximum potential oil recovery?									
Terminal 1	Midnight	IFO-380	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
Top of the crossover (buoy 32-29)	Midnight	IFO-380	1.5 million	Spring Equinox	25th percentile for March - Westport	48	MSRC and NRC	0	1

Location	Time of Day	Oil Type	Spill Volume (gall)	Day /Dark (season)	Wind Speed (knots)	Water Temp. (ºF)	Response Forces	Delay (Hours)	Transit Times w/in GH
Submerged jetty (response inside Harbor)	Midnight	IFO-380	1.5 million	Spring Equinox	25th percentile for March - Westport	48	MSRC and NRC	0	3
How does changing the **oil type** *and* **spill size** affect maximum potential oil recovery?									
Terminal 1	Midnight	IFO-380	500,000	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
Terminal 1	Midnight	IFO-380	1 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.5
How does adding a **dedicated response barge** to the area affect maximum potential oil recovery?									
Terminal 1	Midnight	Diesel	Biodiesel	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC and NRC	0	0.25
Top of the crossover (buoy 32-29)	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Westport	48	MSRC and NRC	0	0.25
Submerged jetty (response inside Harbor)	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Westport	48	MSRC and NRC	0	0.25
How does changing the **recovery systems used** affect the maximum potential oil recovery?									
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	MSRC only	0	0.5
Terminal 1	Midnight	Diesel	1.5 million	Spring Equinox	25th percentile for March - Bowerman Airport	48	NRC only	0	0.5

3.5 BASE CASE INPUTS USED

This section describes the key inputs used for the base case. Variable inputs used in the scenarios are described with scenario results in the next section.

All ROC scenarios use an instantaneous spill (as opposed to a continuous release), the same basic response system attributes (e.g., skimming speed, skimmer efficiency, swath width), and the duration of the simulation (48 hours).

3.5.1 LOCATION, OIL TYPE, AND VOLUME

The base case scenario is at Terminal 1 in the Port of Gray's Harbor. This is the terminal at which tankers are loaded from the REG facility. It is also assumed that recovery systems could offload at this facility when their primary storage fills.

The base case scenario used a 1.5 million gallon diesel spill. The only oils carried as cargo in Grays Harbor are canola oil and biodiesel processed at the REG facility.

ROC includes a routine that models the spread and weathering of oil spilled to water. The ROC routine allows users to draw from a library of oils with their necessary properties pre-loaded, or to enter their own properties for oils that are not already included in the database. Because neither of the non-petroleum oil cargoes in Grays Harbor were already included in the available database, the Department of Ecology sought the necessary details about biodiesel properties both from the producing company and by sending a sample provided by the company for laboratory analysis. However, the lab was unable to conduct the test for necessary distillate cuts needed. Without this information, weathering in the model did not appear accurate: it estimated that the biodiesel would evaporate more rapidly than diesel. Instead, for the purpose of this study, a pre-loaded marine diesel fuel was used as a more likely approximation of how biodiesel would spread and weather.

3.5.2 CONDITIONS (DAYLIGHT, WINDS, WATER TEMPERATURE)

The base case spill was assumed to occur during the Spring Equinox, with daylight (including hours of civil twilight) occurring from 6:48 am until 7:59 pm (REF).

The wind speed used was 6.08 knots. This was the 25th percentile wind speed for spring from Bowerman Airport (meaning that 75% of the time, winds are higher than this and 25% of the time they are lower) based on data collected since 1949. This location was used because of its proximity to the base case spill location and the availability of decades of data from the National Weather Service. Wind speeds are further discussed in Section 4.3.3.

Sea surface temperatures were taken from NOAA satellite readings shown in Figure 3-2.[3] The base case used the average for March (48 F).

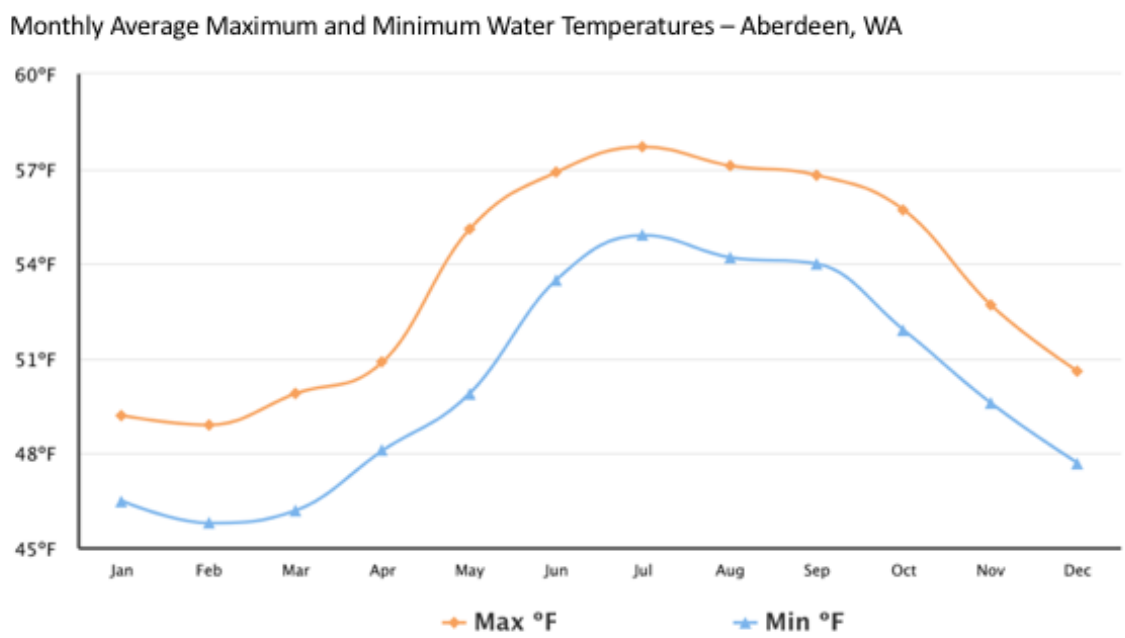

Figure 3-2. Monthly average maximum and minimum surface water temperatures at Aberdeen, WA based on NOAA satellite data (from www.seatemperature.org)

3.5.3 RESPONSE RESOURCES

Response forces are recovery systems consisting of vessels, equipment, and personnel.[4] All of the critical components of a recovery system must be in place and operational for the system to function. This analysis uses existing response resources (personnel, vessels, and equipment) based in Washington and Oregon.

Response contractors are required to provide information to the Department of Ecology describing their equipment and other resources. The Department of Ecology provided information for the Marine Spill Response Corporation (MSRC) and National Response Corporation (NRC) about resources that would be deployed in Grays Harbor for use in this analysis. Nuka Research used this information, filling in gaps needed for the

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[3] Calculated monthly average minimum and maximum taken from https://www.seatemperature.org/north-america/united-states/aberdeen.htm. Website does not give the date range used for calculating averages.

[4] For this analysis, we assume that personnel will be available to mobilize and deploy vessels and equipment.

analysis where necessary. Both organizations helpfully reviewed the specifications for their systems before the analysis was run.

Tables 3-2 and 3-3 list the response systems according to which organization owns the primary vessel (NRC or MSRC) and location of that vessel. Systems are often assembled from resources in different locations and sometimes different ownership. It also indicates the Effective Daily Recovery Capacity (EDRC)[5] and on-board storage volume of the system.

Table 3-2. NRC response systems used in ROC analysis

System Name	On-Board Storage (bbl)	EDRC	Location
Marco/1C #1	268	3588	Seattle, WA
Marco/1C #2	268	3588	Seattle, WA
Lamor/FRV 6	246	6038	Aberdeen, WA
Marco/IC	268	3588	Portland, OR
Marco/I-I	30	3588	St. Helens, OR
Speed Sweep R7	325	128	Seattle, WA
Jet	100	662	Portland, WA
Speed Sweep R12	438	3017	Port Angeles, WA
Cape Flattery	420	2427	Neah Bay, WA
Ironwood	238	1440	Astoria, OR
OSRV NRC 248	30783	24000	Port Angeles, WA

[5] Effective daily recovery capacity (EDRC) is a measure used by both federal regulators and the Department of Ecology to quantify the capability of skimming systems required under regulations. EDRC is a rate, typically expressed in barrels/day, and calculated as 20% of the manufacturer's nameplate recovery rate for the equipment (Department of Ecology, 2013). EDRC measures how quickly the skimming pumps can take up fluid, with a standard reduction from the manufacturer-named rate to acknowledge losses of efficiency. Reductions in efficiency are not quantified beyond the 20% "derating," but could result, for example, from the uptake of water or debris in addition to oil, or oil that escapes recovery or containment.

Table 3-3. MSRC response systems used in ROC analysis

System Name	On-Board Storage (bbl)	EDRC	Location
30-10	24	3588	Portland, OR
PEREGRINE	28	3588	Everett, WA
SANDPIPER	4	10764	Tacoma, WA
OREGON RESPONDER	4000	10567	Astoria, OR
BUSTER #4 (A)	196	0	Neah Bay, WA
BUSTER #4 (B)	196	0	Everett, WA
BUSTER #4 (C)	196	0	Astoria, OR
MINI BARGE A	200	2477	Everett, WA
MINI BARGE B	200	2477	Everett, WA
MINI BARGE C	200	2477	Everett, WA
ARCTIC TERN	276	15840	Neah Bay, WA
WC PARK RESPONDER	14000	10567	Port Angeles, WA
SHEARWATER	1362	12000	Port Angeles, WA
ROYAL TERN	276	6000	Anacortes, WA
OSRB 404	40000	0	Astoria, OR
OSRB 380	38000	0	Port Angeles, WA

ROC requires detailed inputs related to the operation and effectiveness of on-water recovery system in order to estimate how quickly it will recover oil and how much oil (and water) can be recovered before off-loading to secondary storage. Inputs used for each response system analyzed are found in Appendix A. Appendix B shows the timing of each system's deployment for the base case scenario. While most of the information on systems configurations, above, came from the spreadsheets provided to Ecology (and shared with Nuka Research), the information in Table 3-4, below, is drawn primarily from established assumptions in spill response planning manuals and literature.

Table 3-4. Inputs related to response system efficiency in encountering, recovering, and storing oil

FACTOR	EXPLANATION	VALUES USED
Recovery Speed	Advancing speed for on-water response systems (vessels, boom, and skimmers). Speeds vary depending upon the strike team composition based on operating limits of skimming systems. Advancing speeds are important to effective containment of oil; at high speeds, oil will entrain (move under containment boom) and escape recovery.	0.65 knots for J-boom containment systems 1.0 knot for belt-type recovery systems with gated U-boom 2.5 knots for Enhanced Recovery (e.g., Current Buster) containment systems (Based on ROC Technical Manual according to skimmer type)
Swath Width	Swath width is the width of the area within the containment boom along which floating oil is swept. Swath widths vary depending upon the strike team configuration and the environmental conditions.[6] Maintaining larger swaths becomes more difficult as wind, waves, and currents increase. For every foot of swath width, it is industry standard that three feet of containment boom are required.	Boom length is based on system specs Swath width is (1/3) of entire combined boom length
Throughput Efficiency	Throughput efficiency is the proportion of the oil encountered that is recovered. Containment systems do not typically recover 100% of oil that could in theory encountered by a booming system due to a variety of limitations, the most significant being moving through the thickest portion of the slick and loss of contained oil through entrainment (loss of oil below the boom). When tracking and observation fail (such as at night), this is exacerbated by failure to effectively target oil, which results in increasingly sweeping thin, patchy oil or missing the slicks entirely.	75% daylight 35% when oil recovery occurs during darkness
Decant Efficiency	On-water skimming recovers a mix of oil and water. Some of the water collected will be emulsified with oil, and some will remain as free water. Free water may be removed from storage tanks and returned to the sea in process known as decanting. Decanting reduces the total volume of recovered fluids that must be stored. The decant efficiency is the percentage of recovered free water that is separated out from the total recovery volume.	Decanting efficiency will allow for removal of 80% of the free water recovered. Decanting of the relatively uncontaminated recovered water will not be allowed for drogues, bladders, or primary storage devices of less than 10,000 gallons. Unless otherwise specified, decanting rate is assumed to be 440 gal/minute.
Offload Time	Offload time is the amount of time that strike teams must spend offloading recovered fluids from primary to secondary storage. During offloading, the strike team cannot actively recover oil.	Offload times are calculated from given values in the system specs. Onboard storage divided by discharge rate plus 30 minutes
Transit to-and-from Offloading	Transit time is the time required for a vessel to transit from the recovery site to an offload location. A 5-knot speed is assumed in this study.	Base case is 30 min, Top of the Crossover is 1hr, Submerged Jetty s 3hrs. Based on 5 knot speed.*
Recovery Efficiency	Recovery efficiency is the percentage of oil recovered relative to the total volume of fluids recovered. It varies by skimmer type, environmental conditions, and operator proficiency.	Calculated by ROC based on skimmer type, wind speed, and oil viscosity. (ROC nominal default)

*Actual speeds would vary considerably depending on tidal currents.

[6] Based on standard oil spill response tactics guides.

3.6 LIMITATIONS

ROC is a useful tool because it allows for a more nuanced understanding of spill response capacity than just looking at equipment inventories or pump rates and provides an accessible way to explore the potential effects of some variables on a response. However, as with any model it also has limitations which must be understood. These include the fact that ROC does *not*:

- Incorporate location-specific currents, tides, water depth/shoreline, salinity, particulates, debris, or other features which may impact oil slick spread and weathering or response operations.
- Model oil submergence or the impact of wind direction or sea state on slick behavior.
- Allow for variations in wind speed or water temperature during the modeled scenarios. (These are input at the start of the scenario. Different scenarios can be run with different wind speed or water temperature but these variables do not change during a single scenario.)
- Model all aspects of a response, such as the ability to track oil in daylight or darkness (though only systems equipped for operations in darkness are assumed to operate at night), responder skill level, or the impact of conditions such as poor visibility on a response.

In short, ROC is not intended to predict what will happen in any given location or spill situation. It is an analytical tool to provide a simplified model of a response and thus afford the opportunity to examine the impact of a limited set of environmental conditions or response planning decisions on maximum potential response capacity.

4 RESULTS

This section describes the results and underlying drivers of the way scenario results vary from the base case. First, oil weathering for the base case is described. Then the base case results are explained. A comparison of the results for each scenario are presented. Explanations are provided for the variation in modeled results.

4.1 OIL WEATHERING

The way oil spreads and weathers on the water has a significant effect on the response. This section describes the spread and weathering of the diesel used in the base case over 5 days and most of the scenarios *without* any response operations at play. As noted, ROC does not incorporate currents or the significant tides, nor does it include a trajectory model that would indicate where oil would contact the shoreline. Instead, it presents a simplified model of how oil would spread absent these factors. The way the oil slick thins, evaporates, and emulsifies is still important to understand when considering response capacity.

An oil slick will always begin to thin to the extent that any natural confines in an area (ice, shore) allow. Different oils will thin at different rates and this may change over time as other factors such as emulsification come into play. Figure 4-1 shows the thinning of the diesel slick used in the base case scenario.

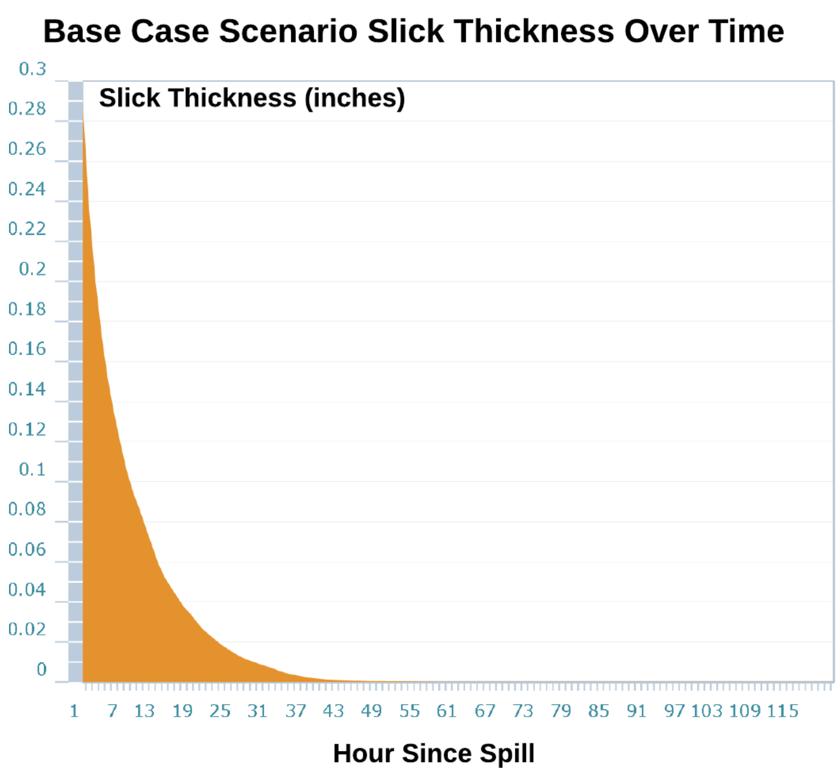

Figure 4-1. Slick thinning based on base case spill scenario with no response included

With diesel fuel, evaporation is a significant effect. Some dispersion into the water column also occurs. (This is referred to as natural dispersion to distinguish it from the chemical dispersion, a response strategy not considered in this study.) See Figure 4-2.

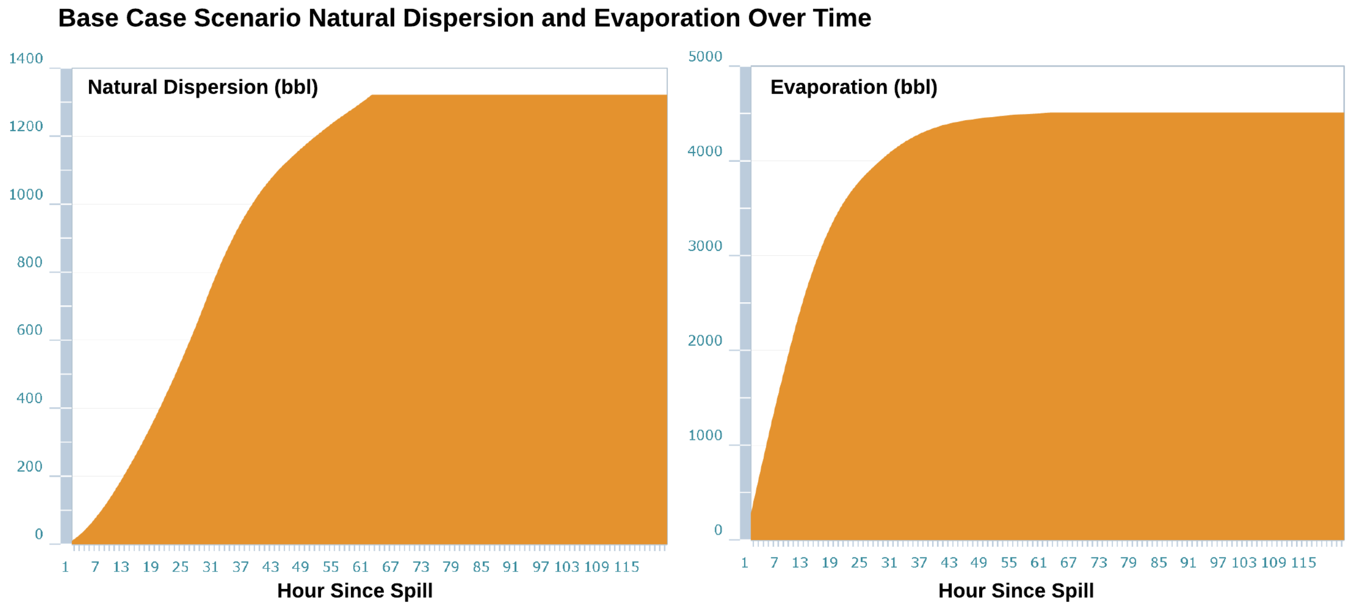

Figure 4-2. Modeled natural dispersion and evaporation based on base case spill scenario with no response included

4.2 BASE CASE RESULTS

The base case scenario was a 1.5 million-gallon diesel spill at the Terminal 1 during the Spring Equinox. At 24 hours after the spill, the maximum recovery estimate was 47%. It reached 82% by 48 hours.

Figure 4-3 shows the estimated maximum volume recovered, along with the volumes evaporated, naturally dispersed, and remaining on the water at the end of 48 hours. Even as the slick thins and becomes harder to collect, recovery ramps significantly as more systems come on-scene. The volume remaining on the water at the end of scenario ultimately thins to an unrecoverable amount.

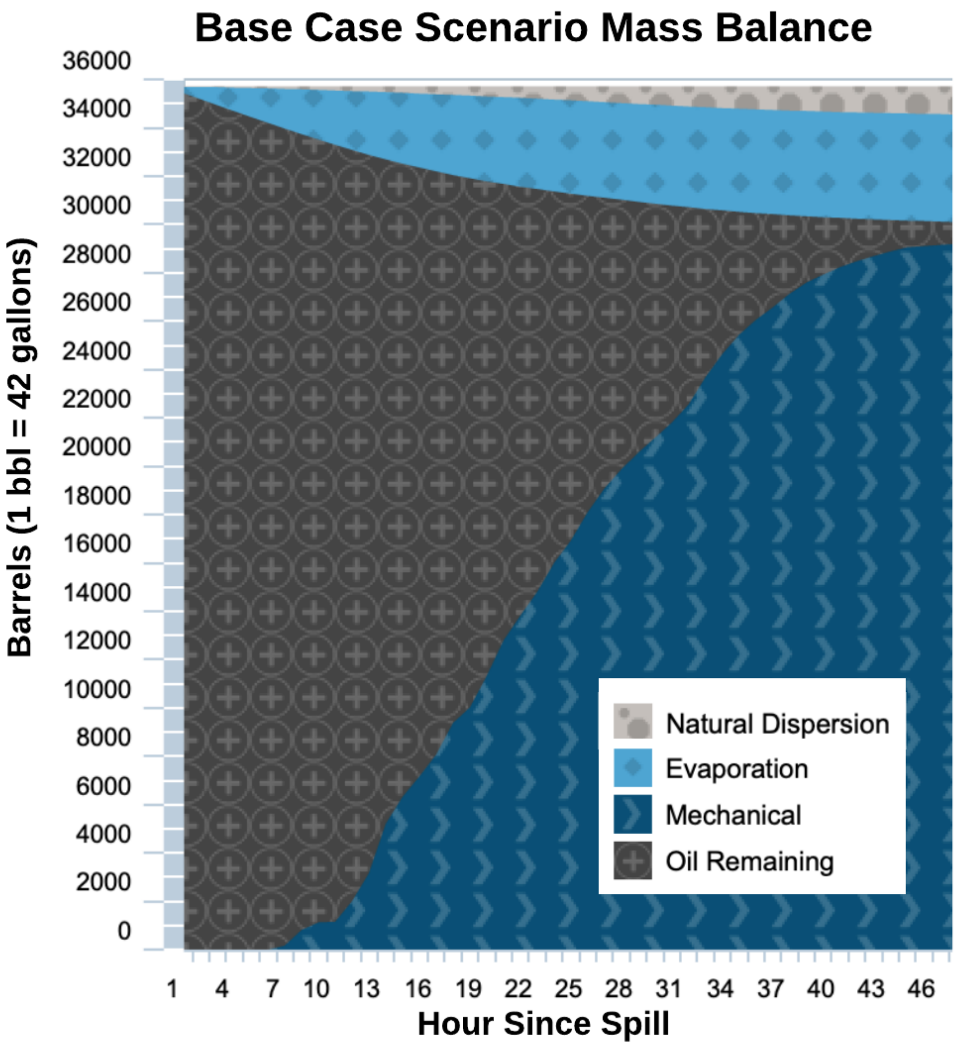

Figure 4-3. Mass balance for base case showing the volume of oil that naturally disperses, evaporates, is recovered, or remains on water over 48

4.3 ANSWERS TO RESEARCH QUESTIONS

This section answers each research question using the ROC results from the scenarios applied to that question. It also discusses the inputs used for each scenario.

The following three figures show the percent of the spill recovered in each of the scenarios as compared to the base case. The scenarios show the percent recovered at 24 hours and 48 hours. As noted, the tidal currents in Grays Harbor also likely mean that by the end of 48 hours, if not well before, most of the oil will have stranded on shore or left the Harbor.

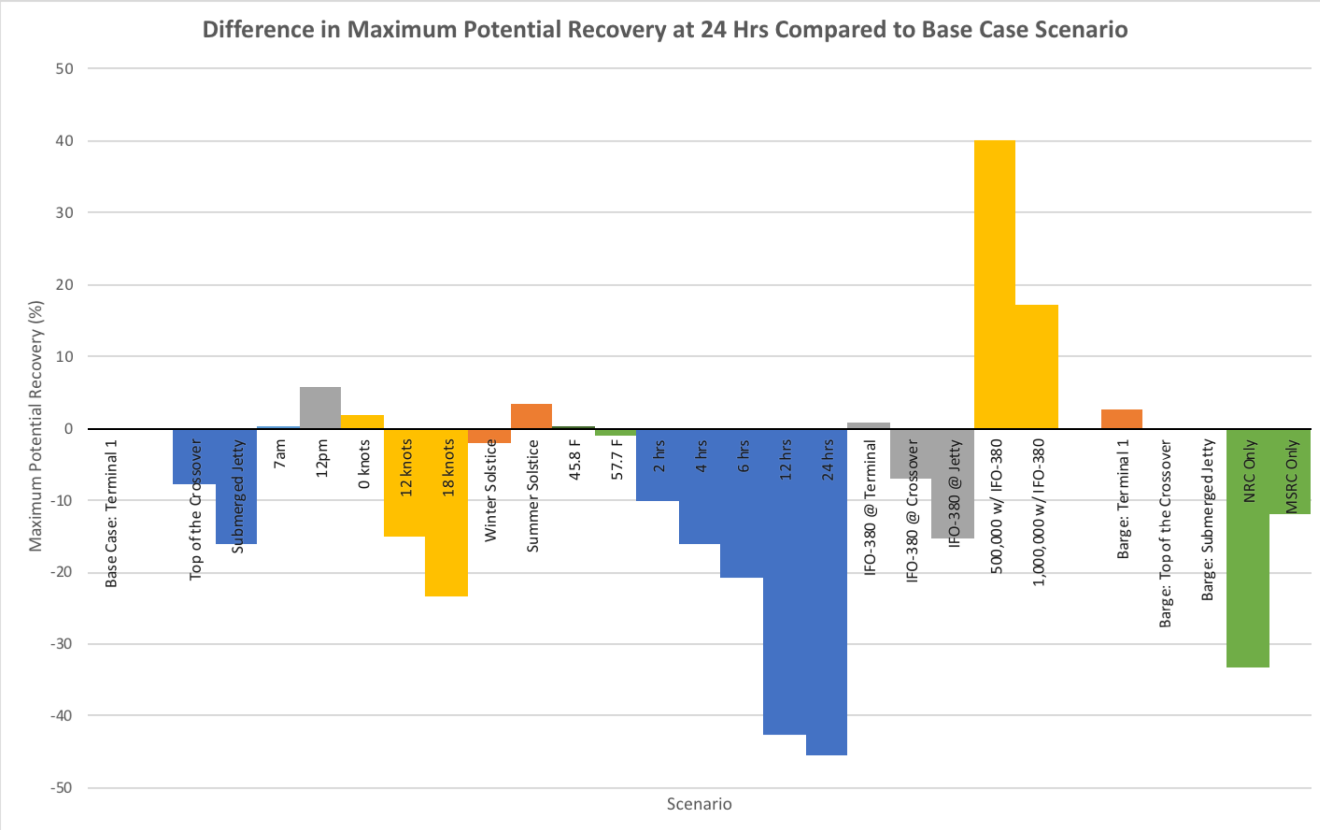

Figure 4-4. Comparison of maximum potential recovery for scenarios relative to the base case – at 24 hours

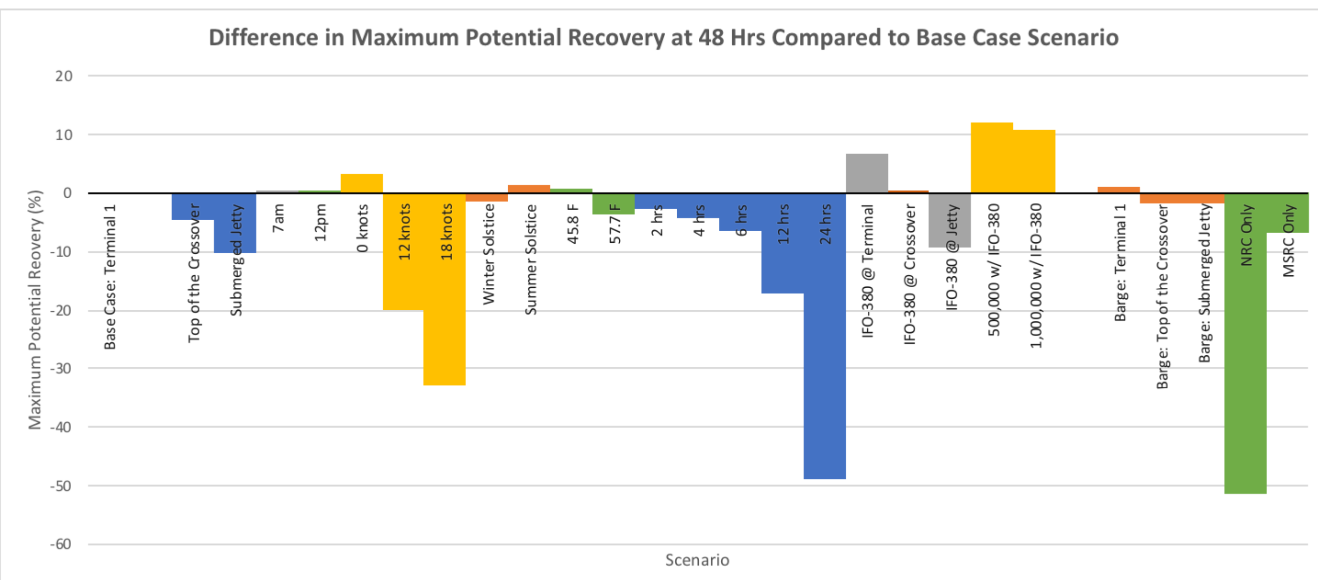

Figure 4-5. Comparison of maximum potential recovery for scenarios relative to the base case – at 24 hours

4.3.1 LOCATION

How does changing the location of the spill within Grays Harbor affect maximum potential oil recovery?

Three spill locations along the shipping route through Grays Harbor were used to answer this question. Figure 4-6 shows these locations. Terminal 1 is the location where bulk oil cargo is loaded in Grays Harbor, the Top of the Crossover in the mid-Harbor is at a sharp turn in the shipping lane, and the Submerged Jetty was considered to be a potential spill area as well. For the purpose of this analysis, the response to the Submerged Jetty spill was assumed to occur primarily inside the Harbor, as if the spill occurred on a flood tide.

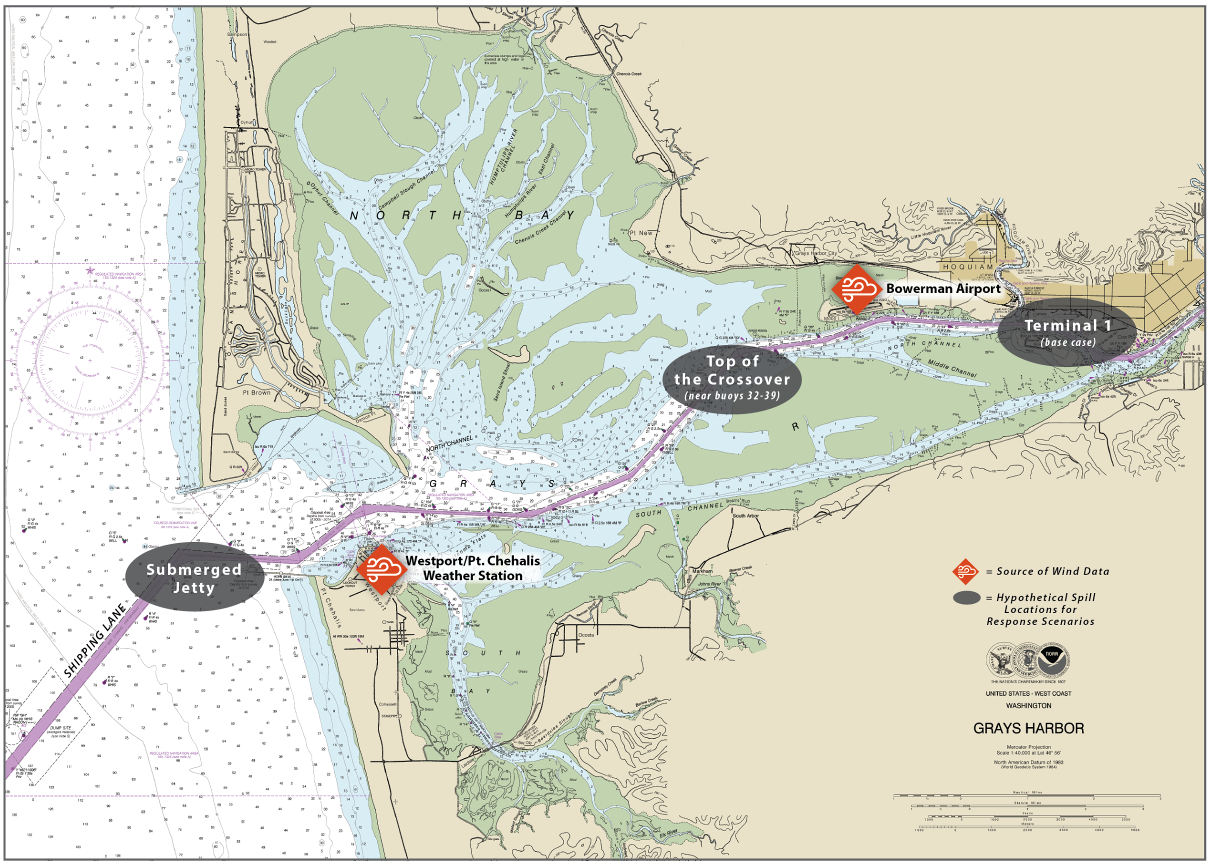

Figure 4-6. Scenario locations used for ROC analysis. The difference in locations relates to the time needed to offload to secondary storage and wind speeds used.

Two variables were adjusted based on location. The first was the amount of time assumed for transit and from secondary storage for offload at Terminal 1 (times to rig/derig and actually offload were not changed from the base case). For the base case, this was assumed to be 30 minutes, 1 hour at the Top of the Crossover, and 3 hours at the response from a Submerged Jetty spill (with the response taking place just inside the Harbor). In the base case scenario, systems offloaded an average of 6 times though this varied widely: some offloaded just once, while some would have done so more than 20 times.

The second variable was wind speed. At the terminal, the 25th percentile wind speed for spring from Bowerman Airport was used (meaning that 75% of the time, winds are higher than this and 25% of the time they are lower). This was a value of 6.08 knots. The other two locations used the 25th percentile wind speed from a land station in Westport, farther to the West near the mouth of the Harbor. This was a value of 7.15 knots. The locations of the weather stations used are shown in the map above. The effect of wind on the response is explored more thoroughly in Section 4.3.3.

Table 4-1. Maximum potential spill recovery at the REG Terminal, Top of the Crossover, and Submerged Jetty for 24 and 48 hours following the spill

Parameter	Transit Time to Secondary Storage Offload	Winds	Maximum Potential Recovery (%)	
			24-hr	48-hr
Terminal 1 (base case)	30 minutes	25th percentile for Bowerman (6.08 knots)	47	82
Top of the Crossover	1 hour	25th percentile at Westport (7.15 knots)	40	77
Submerged Jetty	3 hours	25th percentile at Westport (7.15 knots)	31	72

4.3.2 TIME OF DAY

How does changing the time of day of the spill affect maximum potential oil recovery?

The results show that changing the time of day of the spill does not have a significant impact on recovery, at least during the Spring Equinox used in the base case.

Table 4-2. Maximum potential spill recovery for spills at midnight, 7am, and 12 noon for 24 and 48 hours following the spill

Parameter	Maximum Potential Recovery (%)	
	24-hr	48-hr
Midnight (base case)	47	82
7 am	48	82
12 noon	53	82

4.3.3 WIND SPEED

How does changing the wind speed affect maximum potential oil recovery?

Of the environmental conditions considered, the variation in wind speed had the greatest impact. Higher winds reduce the volume of oil recovered because the slick spreads more quickly. Wind also affects skimming, though the effect is different for different types of skimmers as shown in Figure 4-7 from the ROC manual (Dale, 2011).

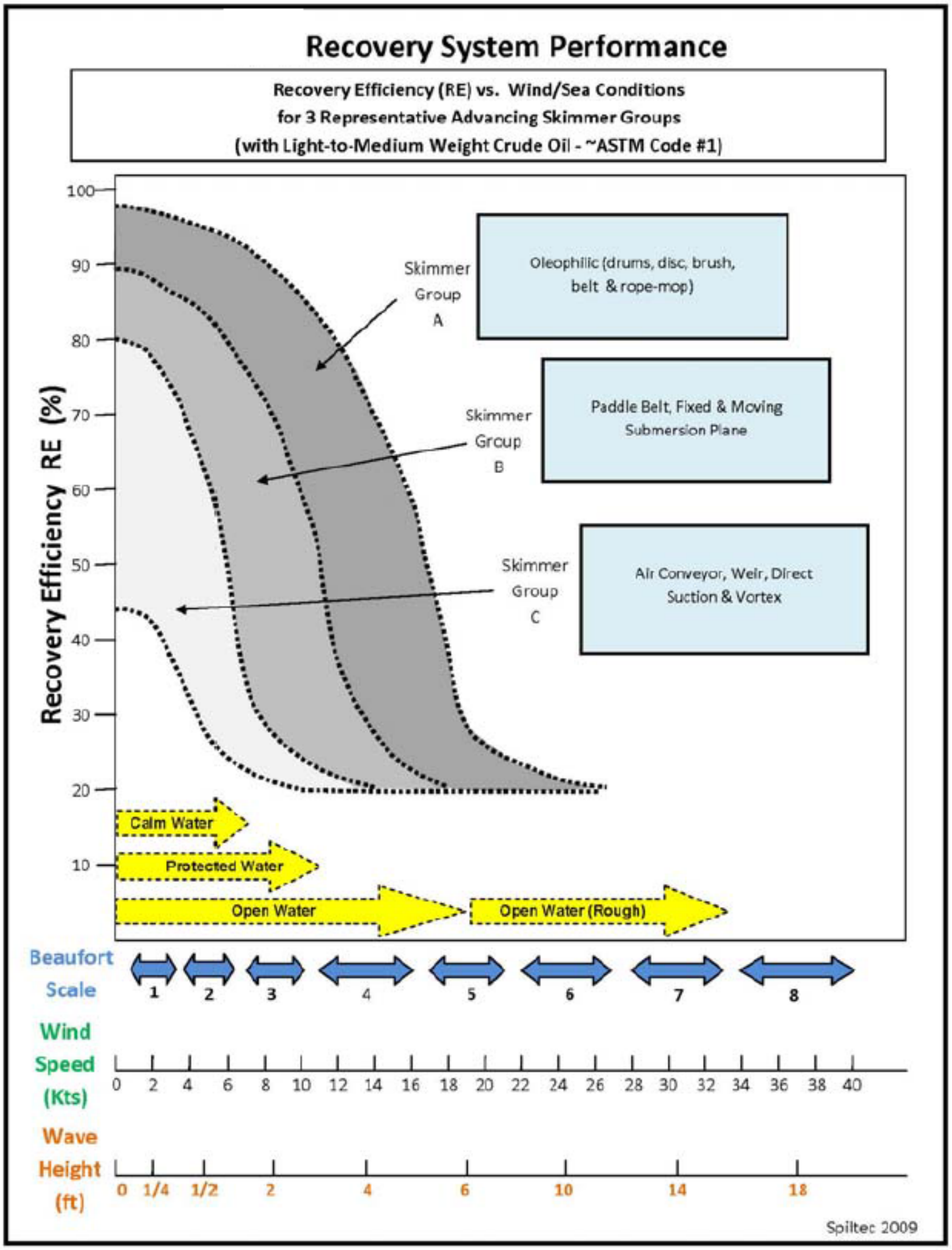

Figure 4-7. Impact of wind conditions on recovery efficiency for different types of skimmers (Dale, 2011)

The base case scenario used 6.08 knot winds, representing the 25th percentile wind speed at Bowerman Airport. Figure 4-8 summarizes wind speeds recorded at Bowerman Airport as well as Westport (near the mouth of the Harbor and used for the scenarios at the Top of the Crossover and Submerged Jetty). The figure uses box-and-whisker plots to show the frequency with which different wind speeds occur in each month. The white stripe in each vertical bar represents the median wind speed, while the vertical line represents the total range of recorded windspeeds. From this, it is clear that the higher wind speed used in the scenarios, 18 knots, are roughly within the 75th percentile of wind speeds at both locations in the winter months. They are less likely in the summer.

Wind speeds for Bowerman Airport (left) and Westport (right)

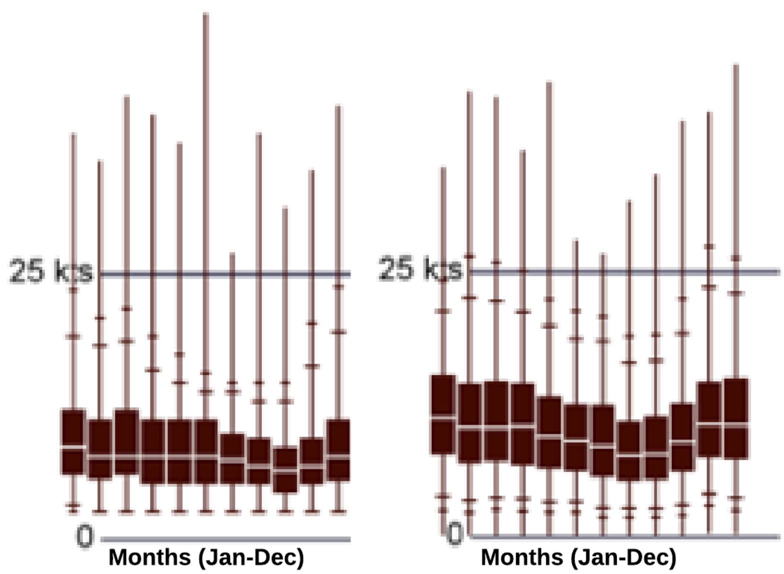

Figure 4-8. Wind speeds for Bowerman Airport (left) and Westport (right). Wind speeds based on National Weather Service data from airport (April 1949-October 2018) and National Data Buoy Center for land-station at Westport (2008-September 2018).

Table 4-3 and Figure 4-9 present the impact of wind conditions on model results. While the difference between 0-6 knots was fairly minimal, winds of 12 knots had a greater impact on potential recovery.

Table 4-3. Maximum potential spill recovery at 24 and 48 hours for different seasons (daylight/darkness only)

Parameter	Maximum Potential Recovery (%)	
	24-hr	48-hr
0 knots	49	85
6.08 knots (base case)	47	82
12 knots	32	62
18 knots	24	49

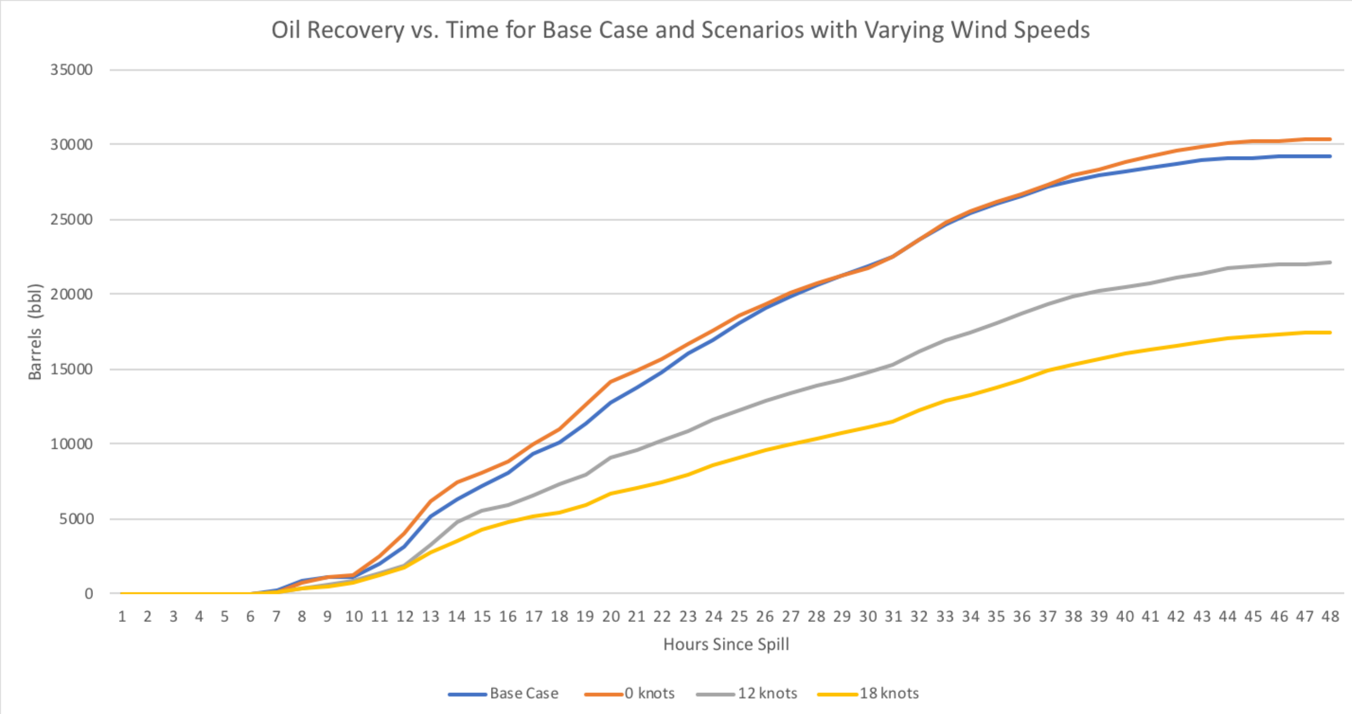

Figure 4-9. Comparison of maximum potential recovery over 48 hours with different wind speeds

4.3.4 DAYLIGHT

How does *changing the amount of daylight affect maximum potential oil recovery?*

Because recovery efficiencies are different during daylight and darkness, recovery estimates are reduced during the winter solstice as compared to the Spring Equinox (base case) or Summer Solstice when daylight is longer. This effect occurs even though many of the systems analyzed in this study are assumed to conduct nighttime recovery operations, though would be much greater if night time operations were not possible. That said, the impact of hours of daylight on recovery operations is less pronounced than other factors, such as wind speed, with less than 10% difference between estimated recovery percentages at the Winter Solstice compared to the Summer Solstice.

Table 4-4. Maximum potential spill recovery at 24 and 48 hours for different seasons (daylight/darkness only)

Parameter	Notes	Maximum Potential Recovery (%)	
		24-hr	48-hr
Spring Equinox (base case)	Equal amounts daylight/darkness	47	82
Winter Solstice	Shortest daylight	45	80
Summer Solstice	Longest daylight	51	83

4.3.5 WATER TEMPERATURE

How does changing the water temperature affect maximum potential oil recovery?

Colder waters slow slick spreading, allowing for slightly higher recovery estimates when the water is colder, though the effect is minimal across the range of water temperatures analyzed. According to the data used (see Section 3.2), sea surface temperature in December (Winter Solstice) is less than in March (Spring Equinox used for base case), so the slight reduction in maximum potential recovery caused by the shorter days (Section 4.3.4) is offset by colder waters in December.

Table 4-5 shows the results for each of the scenarios related to this research question.

Table 4-5. Maximum potential spill recovery at 24 and 48 hours for different water temperatures

Parameter	Notes	Maximum Potential Recovery (%)	
		24-hr	48-hr
48 F (base case)	Monthly average for March	47	82
45.8 F	Monthly average minimum recorded	48	83
57.7 F	Monthly average maximum recorded	46	78

4.3.6 DELAYS

How do delays in response mobilization or deployment affect maximum potential oil recovery?

A response may be delayed by bad weather or planning failures (e.g., inadequate equipment or personnel). Because oil immediately begins spreads and weather when spilled to water, delays mean less oil will be recovered. In the scenarios modeled, even with a 24-hour delay all the recoverable oil would be collected according to model results. However, there is a significant difference from the base case in the percentage recovered at 24 hours (two tidal cycles from the spill) and 48 hours (four tidal cycles) as shown in Table 4-6.

Table 4-6. Maximum potential spill recovery for spills with delays due to weather or planning for 24 and 48 hours following the spill

Parameter	Maximum Potential Recovery (%)	
	24-hr	48-hr
Base case	47	82
2-hr delay	37	79
4-hr delay	31	78
6-hr delay	27	75
12-hr delay	5	65
24-hr delay	2	33

Figure 4-10 shows the mass balance for a scenario with a 2-hour response delay and a 24-hour delay, depicting the change in recovery in the earlier hours of the spill and the impact on the maximum potential recovery by 48 hours.

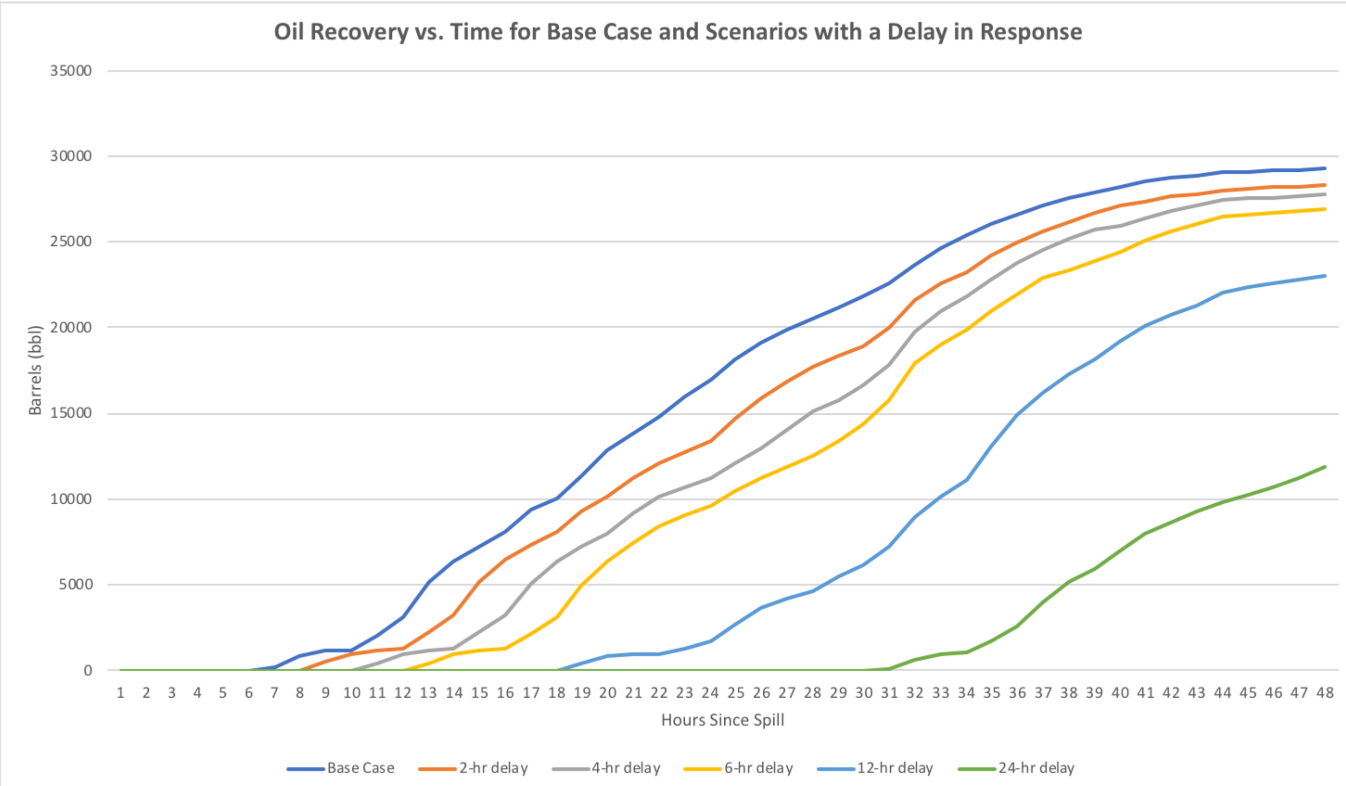

Figure 4-10. Comparison of maximum potential oil recovery for base case and scenarios with response delayed up to 24 hours

4.3.7 OIL TYPE AND SPILL SIZE

Two research questions focused on the use of a different oil type. The base case uses diesel, as discussed previously. IFO-380 is a fuel commonly used by large commercial vessels. The first research question below explores the difference in spill recovery potential with IFO-380 compared to diesel. The second also considers spill volume: because IFO-380 is carried only in vessel fuel tanks in Grays Harbor and not as cargo (in larger quantities), two smaller spill sizes were used.

How does changing the oil type spilled affect maximum potential oil recovery?

As shown in Figure 4-11, diesel evaporates much more quickly than IFO-380. At the same time, both oils will result in a slick that is about the same thickness until around hour 25 (Figure 4-12). After this, the IFO-380 begins to emulsify and thicken the slick. Although this emulsified slick includes water mixed with oil, it still thickens the slick and so increases recovery efficiency after the first 24 hours. This results in a higher percentage of slick recovered for an IFO-380 spill at hour 48 compared to diesel.

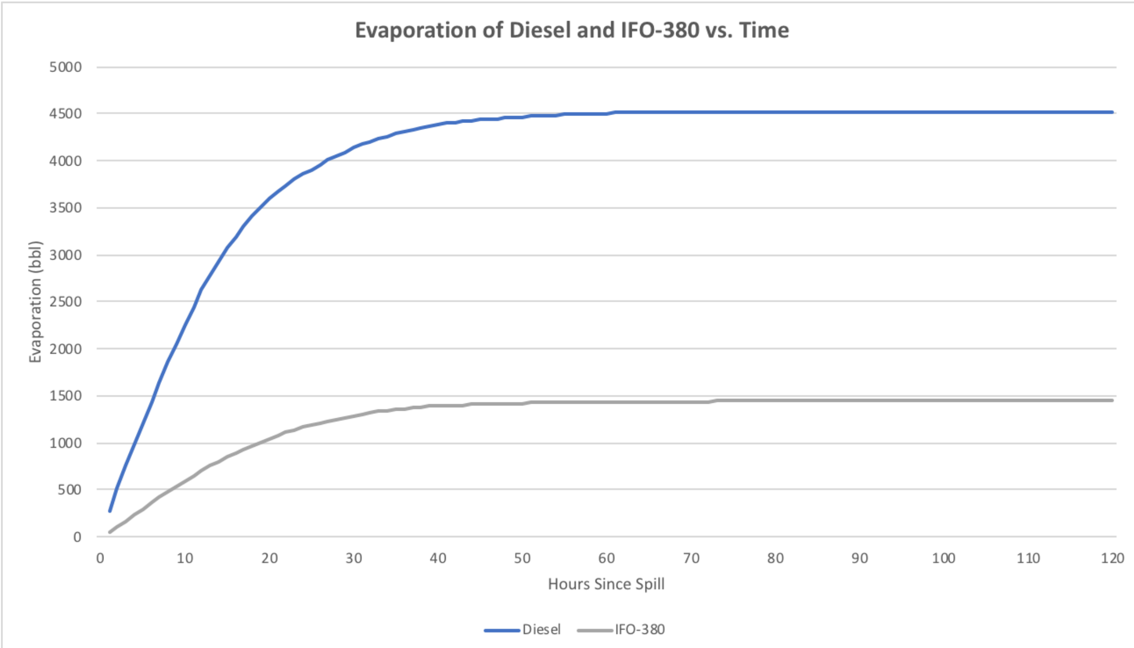

Figure 4-11. Comparison of evaporation over 120 hours (5 days) for diesel and IFO-380 (assuming no response)

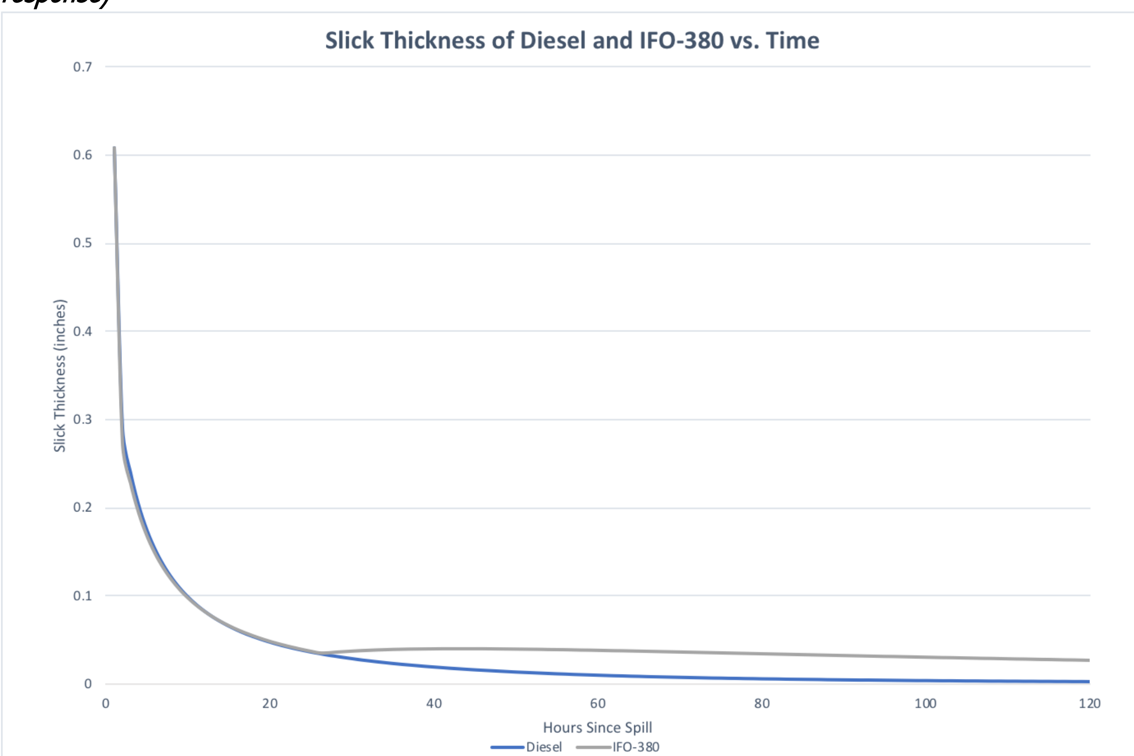

Figure 4-12. Comparison of slick thickness over 120 hours (5 days) for diesel and IFO-380 (assuming no response)

All else being equal, more IFO-380 may be recovered than diesel because of the way the two products spread and weather on water. This effect was evident, if very slight, at all three locations. See Table 4-7 and Figures 4-13 and 4-14.

Table 4-7. Percent of spill potentially recovered at 24 and 48 hours for spills of IFO-380 compared to diesel at the three spill scenario locations

Parameter	Maximum Potential Recovery (%)	
	24-hr	48-hr
REG Terminal (base case)		
Diesel (base case)	47	82
IFO-380	48	89
Top of the Crossover		
Diesel	40	77
IFO-380	40	82
Submerged Jetty		
Diesel	31	72
IFO-380	32	73

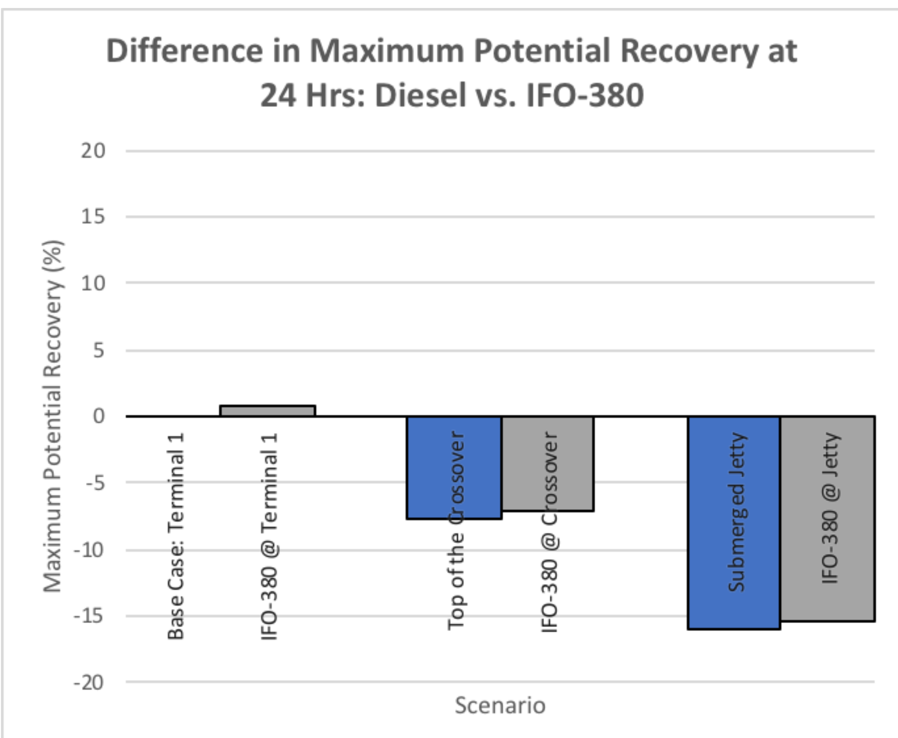

Figure 4-13. Maximum potential recovery at 24 hours for diesel and IFO-380 spills at each location

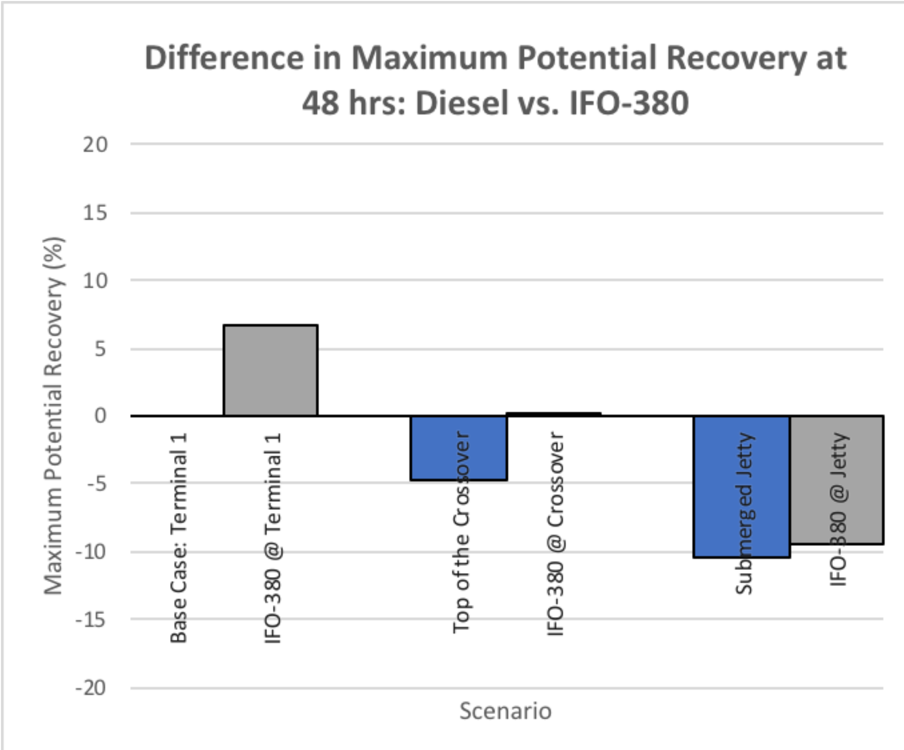

Figure 4-14. Maximum potential recovery at 48 hours for diesel and IFO-380 spills at each location

How does changing the oil type and spill size affect maximum potential oil recovery?

IFO-380 scenarios were also modeled for 500,000 bbl and 1 million bbl in contrast to the 1.5 million spill used for the base case. The maximum percentage recovered is therefore higher since the recovery systems and other inputs are the same, but the spills are larger. The increase in volume recovered was minimal.

4.3.8 RESPONSE RESOURCES

Two research questions addressed response forces directly. One research question considers the impact of adding a hypothetical storage barge to the area. The other considers the impact on recovery if only one response contractor is activated.

How does adding a dedicated response barge to the area affect maximum potential oil recovery?

Secondary storage is a critical component of on-water mechanical oil recovery. If systems do not have a place to offload their primary storage (either on board a vessel or a small storage device towed with the vessel), then recovery must stop until a system can be offloaded. Having secondary storage available when needed is a critical element of maximizing response capacity.

The base case scenario assumed primary storage would be off-loaded at Terminal 1, with a transit time from spill to the terminal 30 min each way (base-case). Offload time is based on primary storage tank size and the offload pump rate plus 30 min to rig/derig the offload set-up. Transit time from the Top of the Crossover is 1 hr. and from the Submerged Jetty is 3 hr., as noted in the location-focused scenarios.

With a response barge added, there was a slight increase in recovery due to reduced transit times to offload. The impact was greater at the Submerged Jetty, which is farther from the Terminal, than at the base case spill site (at Terminal 1) or Top of the Crossover. These results are shown in Table 4-8 and Figures 4-15 and 4-16. The impact was also greater in the first 24 hours; the effect lessened by Hour 48.

Table 4-8. Percent of spill potentially recovered at 24 and 48 hours for spills with and without an additional dedicated secondary storage barge at Terminal 1 (base case), Top of the Crossover, and Submerged Jetty

Parameter	**Maximum Potential Recovery (%)**	
	24-hr	**48-hr**
REG Terminal (base case)		
Current response forces (base case)	47	82
Barge added	50	83
Top of the Crossover		
Current response forces (base case)	40	77
Barge added	47	80
Submerged Jetty		
Current response forces (base case)	31	72
Barge added	47	80

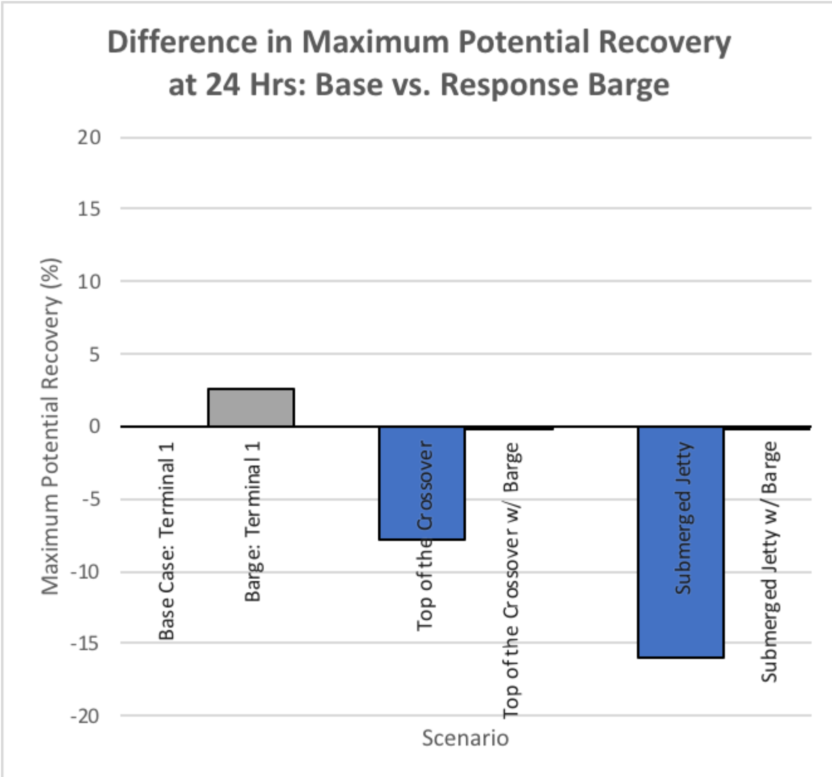

Figure 4-14. Maximum potential recovery at 24 hours with and without the addition of a hypothetical response barge at each location

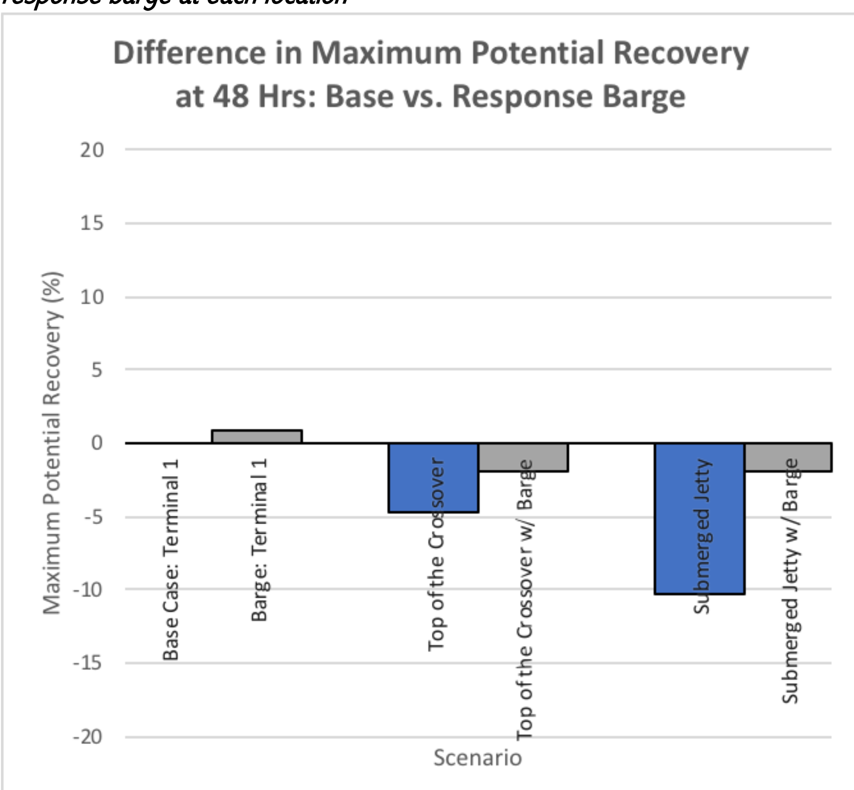

Figure 4-15. Maximum potential recovery at 24 hours with and without the addition of a hypothetical response barge at each location

How does changing the recovery systems used affect maximum potential oil recovery?

This study contemplates a response with both MSRC and NRC involved from the start because it is considering overall response capacity for the region. However, companies are only required to have a contract with one contractor. Using only one organization's resources will reduce the overall response capacity because there will be fewer resources recovering oil. The maximum percentage of the spill recovered with only NRC resources (14% at 24 hours and 31% at 48 hours) is less than the maximum potential capacity with MSRC resources (36% at 24 hours and 75% at 48 hours). The reason for this is that MSRC has more large systems with a higher potential recovery capacity than the NRC systems.

Table 4-9 shows the estimated time on-scene, hours recovering oil (accounting for time to offload), and estimated oil recovery for each system based on the base case scenario results. Results would be different with a different oil or other assumptions.

Table 4-9. Estimated recovery by individual system for base case scenario, including estimated time of arrival (hour since the spill), response organization, time collecting, and oil recovered

Name	Estimated Time of Arrival	Response Org.	Time Collecting (hrs)	Oil Recovered (bbl)
Oregon Responder	10	MSRC	30.83	5893
Shearwater	22	MSRC	26.00	2415
WC Park Responder	21	MSRC	27.00	2187
Buster # 4 B	12	MSRC	29.00	2147
Buster #4 C	12	MSRC	29.00	2147
Buster # 4 A	12	MSRC	30.75	1951
Arctic Tern	16	MSRC	23.85	1092
Royal Tern	23	MSRC	21.33	858
Mini Barge B	12	MSRC	25.28	732
Mini Barge A	12	MSRC	26.50	717
Mini Barge C	12	MSRC	26.50	717
Peregrine	7	MSRC	10.86	561
30-10	6	MSRC	13.21	422
Sandpiper	8	MSRC	4.20	92
Marco/I-I	21	NRC	20.75	1520
Marco/IC #1	6	NRC	20.75	1520
Marco/IC	7	NRC	21.98	1467
Lamor/FRV 6	6	NRC	27.00	921

Name	Estimated Time of Arrival	Response Org.	Time Collecting (hrs)	Oil Recovered (bbl)
Speed Sweep R12	12	NRC	32.50	622
Ironwood	16	NRC	29.33	524
Jet	22	NRC	19.95	522
Speed Sweep R7	7	NRC	30.50	360
Marco/IC #2	6	NRC	7.69	207
Cape Flattery	23	NRC	25.00	140

5 FINDINGS AND CONCLUSION

Nuka Research provides the following overall findings related to the analysis and project:

- A better understanding of biodiesel and canola is needed. This study used diesel as a proxy for biodiesel because the necessary oil properties for biodiesel were not available, but studies of recovery of biodiesel in Grays Harbor or other places it is transported would benefit from having the correct specifications to inform the modeling of weathering and recovery.
- The impact of seasonal variations in daylight and water temperature on response are not significant. Winds, which vary seasonally but could reach 25 knots more any time of year, likely matter much more.
- Adding a response barge for immediate availability of secondary storage does not have a significant impact on maximum potential recovery. Transit times are not long enough from the spill locations analyzed to offloading at the terminal for a barge to make much difference in reducing skimming downtime.

The analysis indicates that if all the response systems are deployed on the timeline indicated in the planning documents under the favorable conditions studied, there is sufficient response capacity to recover more than 80% of a 1.5-million gallon diesel spill in Grays Harbor. This is a very large percentage when compared to actual performance in real spill situations. We suggest that future efforts should focus on validating the timing and assumptions that were inherent in the base case scenario rather than requiring more equipment. Of the factors studied, a delay in the timing of the response was demonstrated to have the most impact in potential oil recovery. A delay of only a few hours can have significant impacts on oil recovery, so it is important to validate that this can be done in the time indicated in the scenarios. While this study did not analyze the following areas, we offer three potential areas to consider for further validation:

- Mobilization and Staging - The process of mobilization and staging necessary to get response forces deployed and operational is necessary to the successful timing of the response. Most of the response systems will be transported by road and launched from Grays Harbor. Ensuring that all these systems can be offloaded and launched in the timeline indicated will therefore be crucial.

- Responders - Twenty-five response systems will require a large number of trained responders. Even the day-light only systems will require two shifts of crew due to the long operational periods (17 hours of daylight). There can be no learning on the job or delays in arrival on-scene with all necessary gear. Responders must be experienced in operating the equipment which they are assigned including in potentially high current environment.
- Offload to Secondary Storage - The analysis assumed that there would be no delays associated with waiting to offload recovered oil to secondary storage, but with 25 active skimming systems there will have to be multiple simultaneous offloads underway.

Response capacity with all systems involved is significant relative to the spill modeled. However, the actual window for recovery is likely very short due to the strong currents and tides. Even without accounting for these local factors, delays had the greatest effect of the variables used in the analysis. Acquiring new equipment is unlikely to make a significant difference, instead, any efforts to improve recovery in Grays Harbor should focus on ensuring that the resources which are available could be deployed as quickly as possible and training in fast current recovery operations.

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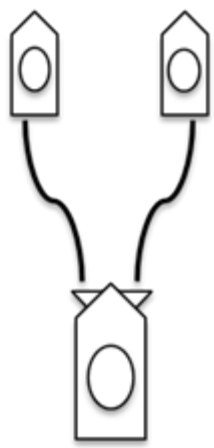
APPENDIX A – RECOVERY SYSTEM SPECIFICATIONS

MSRC SYSTEMS

Recovery System #1: Protected Water, 30-10



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-3 30-10, Marco Skimmer	30802
1	Vessel-SKF-0, Jon Boat #4, JB 15ft/25hp	7487
1	Vessel-SKF-0, Jon Boat #7, JB 14ft/20hp	3150
400	Boom B-2, MSRC-SO2, 20" Curtain	3026

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	6
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	1
Swath Width (feet)	133
Onboard Storage (bbl)	24
Nameplate Pump Rate (bph)	748
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	00:35
NOTES: Protected water waves 0-3 ft, capable of night operations using onboard vessel lighting and navigation equipment. Assume 1-hour MOB time. Swath width for night ops will be decreased to 50 ft.	

Recovery System #2: Protected Water, Peregrine

RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-3 Peregrine, Marco Skimmer	3030
1	Vessel-SKF-0, SNIPE Seine Skiff 18ft.	3152
1	Vessel-SKF-0, JAEGER Seine Skiff 18ft.	3032
600	Boom B-2, MSRC SO2, 20" kepner	3026

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	7
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	28
Nameplate Pump Rate (bph)	748
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	00:35
NOTES: Protected water waves 0-3 ft, capable of night operations using onboard vessel lighting and navigation equipment. Assume 1-hour MOB time.	

Recovery System #3: Protected Water, Sandpiper

RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-3 Sandpiper, Marco Skimmer	3029
1	Vessel-SKF-0, EGRET, Seine Skiff 18ft.	2992
1	Vessel-SKF-0, Willet, Seine Skiff 18ft.	3110
200	Boom B-2 MSRC-SO2, 20" Curtain	3026
400	Boom B-2 MSRC-S25, 20" Curtain	3017

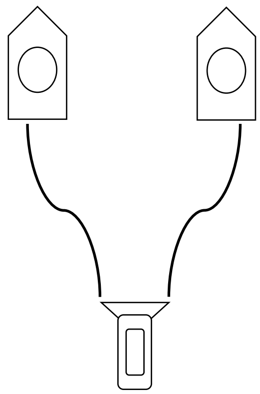
INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	8
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	4
Nameplate Pump Rate (bph)	2,243
Discharge Rate (bph)	360
Decant Rate (bph)	360
Offload Time (hh:mm)	00:35
NOTES: Protected water waves 0-3 ft, capable of night operations using onboard vessel lighting and navigation equipment. Assume 1-hour MOB time.	

Recovery System #4: Open Water,,
Oregon Responder

RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-1, Oregon Responder Transrec Skimmer	7518
1	Vessel WB-3, Oregon Responder 16-1, Workboat 32’	7522
1320	Boom B-1, Oregon Responder, 67”	7514
1	Pump P-3 OSRV, Oregon Responder, CCN 150, 2200 gpm	7516
1	Skimmer-PS-1, OSRV Oregon Responder, STRESS Weir	7519

INPUTS	
Skimmer Group	C
Estimated Time of Arrival (hr)	10
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	0.65
Swath Width (feet)	440
Onboard Storage (bbl)	4,000
Nameplate Pump Rate (bph)	2,201
Discharge Rate (bph)	1,980
Decant Rate (bph)	1,980
Offload Time (hh:mm)	02:35
NOTES: Protected water waves 0-3 ft, capable of night operations using vessel lighting and vessel-based X-band radar and thermal infrared camera. Assume 1-hour MOB time	

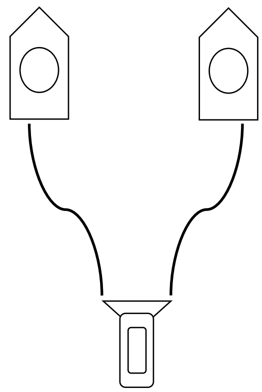
Recovery System #5: Open Water, Buster #4 A



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-WB-3 Angler, VOO/42, 1975, Diesel 525hp	33979
1	Vessel-WB-2 Billie Marie II, VOO/80, 1977 Skolrood, Diesel 350hp	33980
200	Skimmer BO-0 Buster #4, System C	30801
1	Pump-P-4, Shallow Water Barge 23, Pump DOP 250, 440 gpm	7511
1	Skimmer-PS-3, Shallow Water Barge 23, Skimmer QME Tri Brush or Drum	29594
1	Vessel-WB-4, Shallow Water Barge 23, Work Boat WB-29<29’	7555
1	Vessel-TB-4, Shallow Water Barge 23, non	7562

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	2.5
Swath Width (feet)	66.7
Onboard Storage (bbl)	400
Nameplate Pump Rate (bph)	188.5
Discharge Rate (bph)	2,400
Decant Rate (bph)	2,400
Offload Time (hh:mm)	00:45
NOTES: Open water waves 0-6 ft, capable of night operations using lighting and navigation equipment of VOO vessels. Assuming 3 hours MOB.	

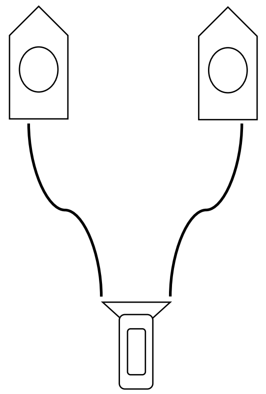
Recovery System #6: Open Water, Buster #4 B



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-WB-4 Drake Teal, VOO/27.5, 1976 Bowpicker, Gas 350	33981
1	Vessel-WB-2 Ranger, VOO/56, 1974 Twin Diesel 525 each	33982
200	Skimmer-BO-0 Current Buster #4	31075
1	Pump-P-4, Shallow Water Barge 25, Pump DOP 250, 440 gpm	29593
1	Skimmer-PS-3, Shallow Water Barge 25, Skimmer GT-185 Brush	7480
1	Vessel-WB-4, Shallow Water Barge 25, Work Boat WB-30<29’	7563
1	Vessel-TB-4, Shallow Water Barge 25, non	7566

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	2.5
Swath Width (feet)	67
Onboard Storage (bbl)	400
Nameplate Pump Rate (bph)	285.6
Discharge Rate (bph)	2,400
Decant Rate (bph)	2,400
Offload Time (hh:mm)	00:45
NOTES Open water waves 0-6 ft, capable of night operations using lighting and navigation equipment of VOO vessels. Assuming 3 hours MOB	

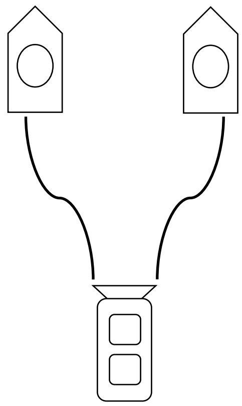
Recovery System #7: Open Water, Buster #4 C



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-WB-3 Rock-N-Roll, VOO/32, 2003 Edwing, 600hp	33983
1	Vessel-WB-2 Tani Rae, VOO/82, 1992 Diesel	33984
200	Skimmer-BO-0 Current Buster #4	31077
1	Pump-P-4, Shallow Water Barge 19, Pump DOP 250, 440 gpm	30987
1	Skimmer-PS-3, Shallow Water Barge 19, Skimmer GT-185 Brush	7553
1	Vessel-WB-4, Shallow Water Barge 19, Work Boat WB-28<29'	7567
1	Vessel-TB-4, Shallow Water Barge 19, non	7554

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	2.5
Swath Width (feet)	67
Onboard Storage (bbl)	400
Nameplate Pump Rate (bph)	285.6
Discharge Rate (bph)	2,400
Decant Rate (bph)	2,400
Offload Time (hh:mm)	00:45
NOTES: Open water waves 0-6 ft, capable of night operations using lighting and navigation equipment of VOO vessels. Assuming 3 hours MOB	

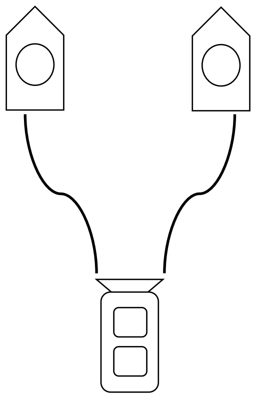
Recovery System #8:
Protected/Shallow Water, Mini Barge A



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-TB-4 Mini Barge A, RD-1, 31' Unpowered	34974
1	Vessel-TB-4 Mini Barge A, SB-1 Skimmer, 31' Unpowered/Lori 2 brush	34973
1	Vessel-WB-4, JE McAmis 24', VOO/J&H Boat Works, crew/workboat, twin outboards 260hp total	32502
1	Vessel-WB-4, JE McAmis 26', VOO/J&H Boat Works, workboat, twin outboards 400hp total	32503

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	0.65
Swath Width (feet)	67
Onboard Storage (bbl)	200
Nameplate Pump Rate (bph)	516
Discharge Rate (bph)	120
Decant Rate (bph)	120
Offload Time (hh:mm)	02:10
NOTES: Protected water waves 0-3 ft, capable of night operations using onboard vessel lighting and navigation equipment. Assuming 1-hour MOB	

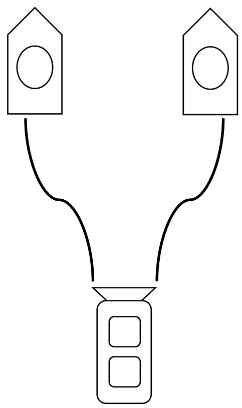
Recovery System #9:
Protected/Shallow Water, Mini Barge B



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-TB-4 Mini Barge B, RD-2, 31' Unpowered	34976
1	Vessel-TB-4 Mini Barge B, SB-2 Skimmer, 31' Unpowered/Lori 2 brush	34975
1	Vessel-WB-2, Four Seasons, VOO/Ben Arthur, flybridge, Diesel outboard 475	32499
1	Vessel-WB-3, Lady Mary, VOO/Edwing Boats, crabber, single Diesel 500hp	32505

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	0.65
Swath Width (feet)	67
Onboard Storage (bbl)	200
Nameplate Pump Rate (bph)	516
Discharge Rate (bph)	120
Decant Rate (bph)	120
Offload Time (hh:mm)	02:10
NOTES: Protected water waves 0-3 ft, capable of night operations using onboard vessel lighting and navigation equipment. Assuming 1-hour MOB	

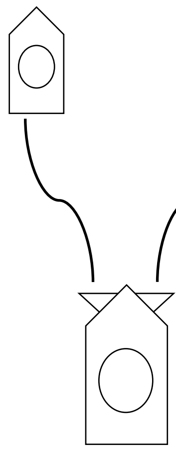
Recovery System #10:
Protected/Shallow Water, Mini Barge C



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-TB-4 Mini Barge C, RD-3, 31' Unpowered	34978
1	Vessel-TB-4 Mini Barge C, SB-3 Skimmer, 31' Unpowered/Lori 2 brush	34977
1	Vessel-WB-3, NAUTI-LADY, VOO/Rawson, single diesel inboard 425hp	32507
1	Vessel-WB-2, Pacific Venture, VOO/Fergason, seiner, single diesel inboard, 440 hp	32508

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	0.65
Swath Width (feet)	67
Onboard Storage (bbl)	200
Nameplate Pump Rate (bph)	516
Discharge Rate (bph)	120
Decant Rate (bph)	120
Offload Time (hh:mm)	02:10
NOTES: Protected water waves 0-3 ft, capable of night operations using onboard vessel lighting and navigation equipment. Assuming 1-hour MOB	

Recovery System #11: Open Water, Arctic Tern



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-2, Arctic Tern, Skimmer JBF	3108
1	Skimmer PS-1, Arctic Tern, Skimmer Stress Weir	7528
1	Vessel-SKF-0, JB-1, VOO/Pacific, keflerm 150hp	32501
1	Vessel-SKF-0, Jon Boat #3, JB 15ft/20hp	24757
400	Boom B-2 MSRC-S25, 20" Curtain	3017

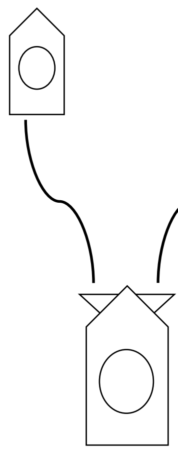
INPUTS	
Skimmer Group	C
Estimated Time of Arrival (hr)	16
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	1.
Swath Width (feet)	133
Onboard Storage (bbl)	276
Nameplate Pump Rate (bph)	3,300
Discharge Rate (bph)	720
Decant Rate (bph)	720
Offload Time (hh:mm)	00:55
NOTES: Open water waves 0-6 ft, capable of night operations using vessel lighting and vessel-based thermal infrared camera. Assuming 1-hour MOB	

Recovery System #12: Open Water, WC Park Responder

RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-1, WC Park Responder, Skimmer Transrec	7527
1	Vessel WB-3, WC Park Responder 15-1, Workboat 32'	7531
1320	Boom B-1, WC Park Responder, 67"	7523

INPUTS	
Skimmer Group	C
Estimated Time of Arrival (hr)	21
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	0.65
Swath Width (feet)	440
Onboard Storage (bbl)	14,000
Nameplate Pump Rate (bph)	2,201
Discharge Rate (bph)	1,980
Decant Rate (bph)	1,980
Offload Time (hh:mm)	07:35
NOTES: Open water waves 0-6 ft, capable of night operations using vessel lighting and vessel-based X-band radar and thermal infrared camera. Assuming 1-hour MOB	

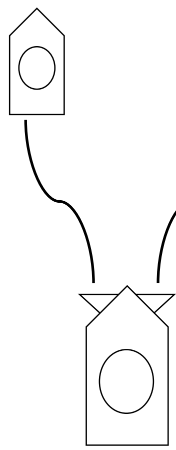
Recovery System #13: Open Water, Shearwater



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel OSRV-1, Shearwater, Skimmer JBF	3104
1	Vessel-WB-3, Osprey, Workboat 42'	2983
600	Boom B-2, Osprey, Kepner 20"	2984
1	Vessel-WB-3, 33' Aluminum Kingcraft Workboat	31215
600	Boom B-2, Shearwater, ACME 30"	3105

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	22
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	1
Swath Width (feet)	400
Onboard Storage (bbl)	1,362
Nameplate Pump Rate (bph)	2,500
Discharge Rate (bph)	720
Decant Rate (bph)	720
Offload Time (hh:mm)	02:25
NOTES: Open water waves 0-6 ft, capable of night operations using vessel lighting and vessel-based thermal infrared camera. Assuming 3-hour MOB	

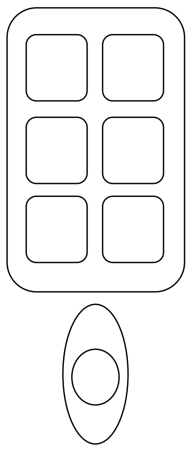
Recovery System #14: Open Water, Royal Tern



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-OSRV-2, Royal Tern, Skimmer JBF	2990
1	Vessel-WB-3, Scoter, Work Boat 34’	3142
1	Vessel-WB-4, Response 5, Work Boat 28’	7490
600	Boom B-2, Scoter, ACME 18”	3012

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	23
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC Specifies
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	276
Nameplate Pump Rate (bph)	1,250
Discharge Rate (bph)	720
Decant Rate (bph)	720
Offload Time (hh:mm)	00:55
NOTES: Open water waves 0-6 ft, capable of night operations using vessel lighting and vessel-based thermal infrared camera. Assuming 1-hour MOB	

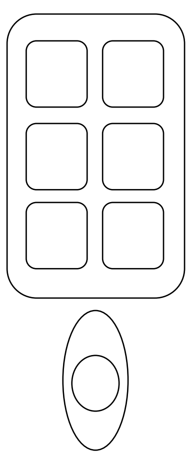
Recovery System #15: Open Water On-Water Storage, OSRB 404



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel TB-2, OSRB 404, Tank Barge	7513
1	Vessel, TUG-2, LOI, >1500hp	LOI

INPUTS	
Skimmer Group	Storage
Estimated Time of Arrival (hr)	23
Throughput efficiency daylight	N/A
Throughput efficiency darkness	N/A
Oil Recovery efficiency	N/A
Skimming Speed (knots)	N/A
Swath Width (feet)	N/A
Onboard Storage (bbl)	40,000
Nameplate Pump Rate (bph)	N/A
Discharge Rate (bph)	5,400
Decant Rate (bph)	N/A
Offload Time (hh:mm)	07:55
NOTES: Open water waves 0-6 ft, capable of night operations using onboard lighting. Assuming 3-hour MOB.	

Recovery System #16: Open Water On-Water Storage, OSRB 380

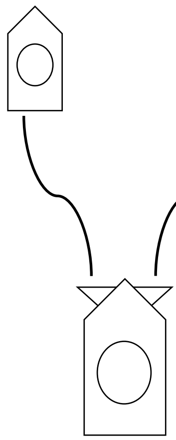


RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel TB-2, OSRB 380, Tank Barge	7510
1	Vessel, TUG-2, LOI, >1500hp	LOI

INPUTS	
Skimmer Group	Storage
Estimated Time of Arrival (hr)	40
Throughput efficiency daylight	N/A
Throughput efficiency darkness	N/A
Oil Recovery efficiency	N/A
Skimming Speed (knots)	N/A
Swath Width (feet)	N/A
Onboard Storage (bbl)	38,000
Nameplate Pump Rate (bph)	N/A
Discharge Rate (bph)	5,400
Decant Rate (bph)	N/A
Offload Time (hh:mm)	07:35
NOTES: Open water waves 0-6 ft, capable of night operations using onboard lighting. Assuming 3-hour MOB.	

NRC SYSTEMS

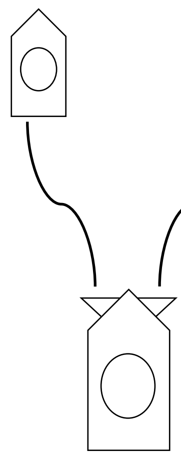
Recovery System #1:
Protected/Shallow Water, Marco/1C, #1



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-OSRV-4, Belt Skimmer Vessel (6059), Marco/1C,#1	28263
1000	Boom-B-3, Contractor boom (Beaver). 10" Acme	27857
1	Vessel-WB-4 26' FRV-Splasher w/ (2) 90 HP outboards	29688
800	Boom-B-2, American Marine 20"	31013
1	Vessel-TB-4 Shallow Water Barge Set 1, 238 bbl, 100 ft Boom	30792

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	6
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	268
Nameplate Pump Rate (bph)	207
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	01:05
NOTES: Protected water waves 0-3 ft. This recovery system is not capable of night operations.	

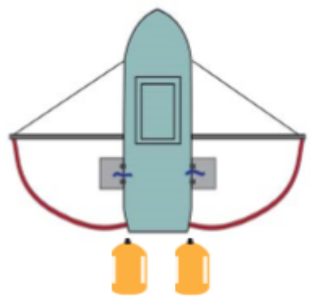
Recovery System #2:
Protected/Shallow Water, Marco/1C #2



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-OSRV-4, Belt Skimmer Vessel (6060), Marco/1C #2	28264
1	Vessel-WB-4, Jetcraft, Workboat 20’	28535
1	Vessel-WB-4, Pacman, 23’ Munson Landing Craft w/ twin 90 HP	28558
1	Vessel-TB-4 Shallow Water Barge Set 4, 238 bbl, 100 ft Boom	31802
1000	Boom-B-2, Contractor Boom, 20” Acme	27912

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	6
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	268
Nameplate Pump Rate (bph)	207
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	01:05
NOTES: Protected water waves 0-3 ft. This recovery system is not capable of night operations.	

Recovery System #3:
Protected/Shallow Water, Lamor/FRV 6

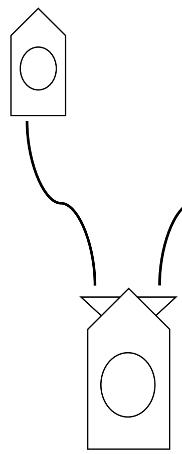


RESOURCES		
No.	*Identification*	*WRRL*
1	Skimmer-PS-2, Portable, Brush Skimmer, Lamor/OPC2	28213
1	Skimmer-PS-2, Portable, Trailer Pier 90, Brush Skimmer, Lamor/OPC2	28214
1	Vessel-WB-3, FRV 6, Kvichak, Response Vessel 32'	28573
1	Storage-PS-4, Portable Tank, LiquidTote, DOT approved	28307
1	Vessel-TB-4, Shallow Water Barge Set 3, Shallow Water Barge Set, 238bbl, 100 ft boom	31801

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	6
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	0.65
Swath Width (feet)	33.3
Onboard Storage (bbl)	246
Nameplate Pump Rate (bph)	1257.9
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	01:05

NOTES: Protected water waves 0-3 ft. This recovery system is not capable of night operations.

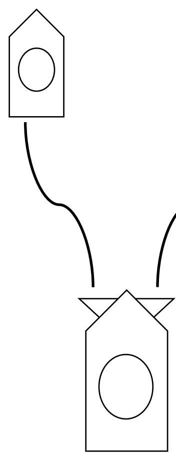
Recovery System #4:
Protected/Shallow Water, Marco/IC



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-OSRV-3, Trailer 6169, Belt Skimmer Vessel, Marco/IC	28261
1	Vessel-WB-4, LUND skiff 6461, Workboat 20'	29788
1	Vessel-WB-4, JETCRAFT 6464 (#9), Workboat 20'	28541
1	Vessel-TB-4, Shallow Water Barge Set 6 238bbl, 100 ft boom	31804
600	Boom-B-2, Contractor boom (3277), 20" Kepner	27876

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	7
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	268
Nameplate Pump Rate (bph)	207
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	01:05
NOTES: Protected water waves 0-3 ft. This recovery system is not capable of night operations.	

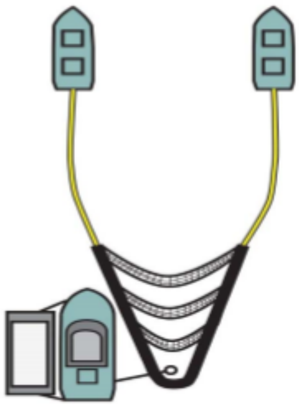
Recovery System #5:
Protected/Shallow Water, Marco/I-I



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-OSRV-3, Belt Skimmer Vessel, BeachMaster/Marco/I-I	28262
1	Vessel-WB-4, Work Skiff # 3 (WS 3), 18' Willipa 90hp outboard	29779
1	Vessel-WB-4, Work skiff #5, 18' Willipa 90hp outboard	29782
600	Boom-B-2, Contractor boom (3277), 20" Kepner	27876

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	21
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	1
Swath Width (feet)	200
Onboard Storage (bbl)	30
Nameplate Pump Rate (bph)	207
Discharge Rate (bph)	480
Decant Rate (bph)	480
Offload Time (hh:mm)	00:35
NOTES: Protected water waves 0-3 ft. This recovery system is not capable of night operations.	

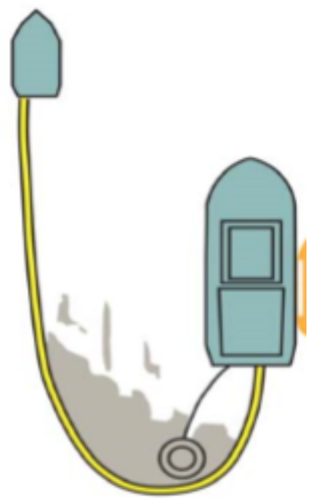
Recovery System #6: Open Water, Speed Sweep R7



RESOURCES		
No.	*Identification*	*WRRL*
200	Boom-B-2, Speed Sweep collection system, Desmi	32319
1	Pump-P-5, Diaphragm, 3" Diesel Loadstar	28186
1	Pump-P-5, Diaphragm, 3" Diesel Wacker	29790
1	Skimmer-PS-4, Portable, Weir Skimmer (6330), 3" Skim-pak 81300	28249
1	Vessel-WB-4, Sea Hawk, 28' Union bay / twin 150hp	28561
1	Vessel-WB-4, Sea Falcon, 28' Union bay / twin 150hp	29783
1	Storage-PS-4, Bladder Tank, Canflex/DLE-4	28270
1	Storage-PS-4, Bladder Tank, Canflex/DLE-4	28271
1	Storage-PS-4, Bladder Tank, Canflex/DLE-4	28272
1	Storage-PS-4, Bladder Tank, Canflex/DLE-4	28273
1	Storage-PS-4, Bladder Tank, Canflex/DLE-4	28274

INPUTS	
Skimmer Group	C
Estimated Time of Arrival (hr)	7
Throughput efficiency daylight	75%
Throughput efficiency darkness	N/A
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	0.65
Swath Width (feet)	66.7
Onboard Storage (bbl)	325
Nameplate Pump Rate (bph)	75
Discharge Rate (bph)	2400
Decant Rate (bph)	2150
Offload Time (hh:mm)	00:45
NOTES Open water waves 0-6 ft. This recovery system is not capable of night operations.	

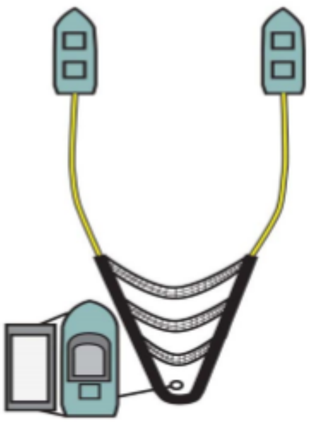
Recovery System #7: Open Water, Jet



RESOURCES		
No.	*Identification*	*WRRL*
1	Skimmer-PS-3, Portable, Brush/Drum Skimmer, Aqua-Guard/RBS-10	28215
1	Vessel-WB-2, Jet, VOO/ 60-69, 2007 Edwing , Jet - 330 hp	33976
1	Vessel-WB-3, Raider 6028, Response Vessel 34'	28575
800	Boom-B-2, Contractor boom (3277), 20" Kepner	27876
1	Vessel-TB-4, Shallow Water Barge Set 5 238bbl, 100 ft boom	31803

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	22
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	0.65
Swath Width (feet)	200
Onboard Storage (bbl)	100
Nameplate Pump Rate (bph)	137.9
Discharge Rate (bph)	600
Decant Rate (bph)	600
Offload Time (hh:mm)	00:45
NOTES: Open water waves 0-6 ft. This storage system is capable of night operations using lighting and navigation equipment of VOO vessels.	

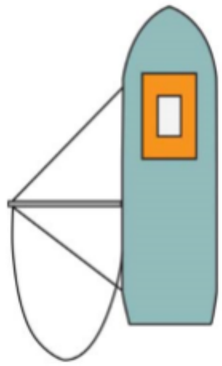
Recovery System #8: Open Water, Speed Sweep R12



RESOURCES		
No.	*Identification*	*WRRL*
200	Boom-B-2, Speed Sweep collection System, Desmi	31493
1	Skimmer-PS-2, Portable, Wier Skimmer (6156), Desmi 250	28253
1	Pump-P-5, Diaphragm, 3" Diesel Wacker	31783
1	Vessel-WB-2, Hawks Point, VOO/ 60-69, 1990, 400hp	33978
1	Vessel-WB-2, Eagle Point, VOO/ 60-69, 1992, Two diesels, 160hp	33977
1	Vessel-TB-4, Shallow Water Barge Set 2 238bbl, 100 ft boom	30267
1	Vessel-WB-4, Miss Annika, VOO/ 28', 1988 J&H Boal Works Gillnetter, 375hp inboard/outboard mercruiser	33987

INPUTS	
Skimmer Group	C
Estimated Time of Arrival (hr)	12
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	0.65
Swath Width (feet)	33.3
Onboard Storage (bbl)	438
Nameplate Pump Rate (bph)	437
Discharge Rate (bph)	2400
Decant Rate (bph)	2150
Offload Time (hh:mm)	00:45
NOTES: Open water waves 0-6 ft. This storage system is capable of night operations using lighting and navigation equipment of VOO vessels.	

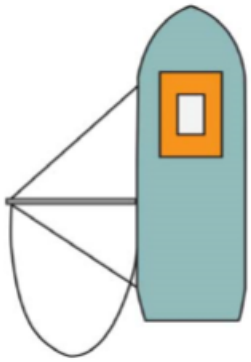
Recovery System #9: Open Water, Cape Flattery



RESOURCES		
No.	*Identification*	*WRRL*
1	Skimmer-PS-3, Brush Skimmer, OSRV Cape Flattery, Aquaguard RBS-40	28259
1	Vessel-OSRV-1, OSRV Cape Flattery, Response Vessel 110'	28537
1	Storage-PS-4, Bladder Tank, (OSRV Cape Flattery), Dracone Canflex	28308
300	Boom-B-1, Inflatable skimming boom, OSRV Cape Flattery, 42" Abasco	27894

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	23
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	0.65
Swath Width (feet)	40
Onboard Storage (bbl)	420
Nameplate Pump Rate (bph)	505.6
Discharge Rate (bph)	1980
Decant Rate (bph)	1980
Offload Time (hh:mm)	00:45
NOTES: Open water waves 0-6 ft. This recovery system is capable of night operations using vessel lighting and vessel-based X-band radar and thermal infrared camera.	

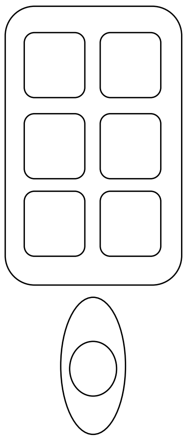
Recovery System #10: Open Water, Ironwood



RESOURCES		
No.	*Identification*	*WRRL*
1	Skimmer-PS-3, Portable, Ironwood, Coated Disc Skimmer, Crucial 13/30 Disk Skimmer	30322
1	Vessel-WB-1, Ironwood, VOSS, 180' Vessel of Opportunity Skimming System	31527
1	Storage-PS-4, Bladder Tank, Canflex/FCB-935-4300	34018
175	Boom-B-1, Ironwood, Inflatable High Sprint, 59	30321

INPUTS	
Skimmer Group	A
Estimated Time of Arrival (hr)	16
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	0.65
Swath Width (feet)	58.3
Onboard Storage (bbl)	238
Nameplate Pump Rate (bph)	171
Discharge Rate (bph)	214
Decant Rate (bph)	214
Offload Time (hh:mm)	01:40
NOTES: Open Water waves 0-6 ft. This recovery system is capable of night operations.	

Recovery System #11: Open Water, OSRV NRC 248



RESOURCES		
No.	*Identification*	*WRRL*
1	Vessel-TB-2, OSRB, NRC 248, Tank Barge	31491
1	Vessel-OSRV-4, Barge, Belt Skimmer, Marco Class XI	32848
1	Vessel, TUG-2, LOI, >1,500 HP	LOI

INPUTS	
Skimmer Group	B
Estimated Time of Arrival (hr)	23
Throughput efficiency daylight	75%
Throughput efficiency darkness	35%
Oil Recovery efficiency	ROC INPUT
Skimming Speed (knots)	1
Swath Width (feet)	0
Onboard Storage (bbl)	30783
Nameplate Pump Rate (bph)	5000
Discharge Rate (bph)	5400
Decant Rate (bph)	5400
Offload Time (hh:mm)	06:15
NOTES: Open water waves 0-6 ft. This storage system is capable of night operations using onboard lighting.	

APPENDIX B – SYSTEM TIMING (BASE CASE)

Spring Equinox 6:48am to 7:59 pm

Spill at 12 am

Day	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 am
Day 1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Day 2	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48

SYSTEM	ETA	OSRO	Day 1	Day 2
30-10 Daylight	6	MSRC	6:45 am to 8:00 pm	6:45 am to 8:00 pm
30-10 Night (AM)	6	MSRC		12:00 am to 6:45 am
30-10 Night (PM)	6	MSRC	8 pm to 12 am	8 pm to 12 am
Arctic Tern Daylight	16	MSRC	4 pm to 8 pm	6:45 am to 8:00 pm
Arctic Tern Night (AM)	16	MSRC		12:00 am to 6:45 am
Arctic Tern Night (PM)	16	MSRC	8 pm to 12 am	8 pm to 12 am
Buster #4 A Daylight	12	MSRC	12 pm to 8 pm	6:45 am to 8:00 pm
Buster # 4 A Night (AM)	12	MSRC		12:00 am to 6:45 am
Buster # 4 A Night (PM)	12	MSRC	8 pm to 12 am	8 pm to 12 am
Buster #4 B Daylight	12	MSRC	12 pm to 8 pm	6:45 am to 8:00 pm
Buster # 4 B Night (AM)	12	MSRC		12:00 am to 6:45 am
Buster # 4 B Night (PM)	12	MSRC	8 pm to 12 am	8 pm to 12 am
Buster #4 C Daylight	12	MSRC	12 pm to 8 pm	6:45 am to 8:00 pm
Buster #4 C Night (AM)	12	MSRC		12:00 am to 6:45 am
Buster #4 C Night (PM)	12	MSRC	8 pm to 12 am	8 pm to 12 am
Cape Flattery Daylight	23	NRC		6:45 am to 8:00 pm
Cape Flattery Night (AM)	23	NRC		12:00 am to 6:45 am
Cape Flattery Night (PM)	23	NRC	11pm to 12 am	8 pm to 12 am
Ironwood Daylight	16	NRC	4 pm to 8 pm	6:45 am to 8:00 pm
Ironwood Night (AM)	16	NRC		12:00 am to 6:45 am
Ironwood Night (PM)	16	NRC	8 pm to 12 am	8 pm to 12 am
Jet Daylight	22	NRC		6:45 am to 8:00 pm
Jet Night (AM)	22	NRC		12:00 am to 6:45 am
Jet Night (PM)	22	NRC	10 pm to 12	8 pm to 12 am
Lamor/FRV 6 Daylight	6	NRC	6:45 am to 8:00 pm	6:45 am to 8:00 pm
Marco/I-I Daylight	21	NRC		6:45 am to 8:00 pm
Marco/IC #1 Daylight	6	NRC	6:45 am to 8:00 pm	6:45 am to 8:00 pm
Marco/IC #2 Daylight	6	NRC	6:45 am to 8:00 pm	6:45 am to 8:00 pm
Marco/IC Daylight	7	NRC	7 am to 8:00 pm	6:45 am to 8:00 pm
Mini Barge A Daylight	12	MSRC	12 pm to 8 pm	6:45 am to 8:00 pm
Mini Barge A Night (AM)	12	MSRC		12:00 am to 6:45 am
Mini Barge A Night (PM)	12	MSRC	8 pm to 12 am	8 pm to 12 am
Mini Barge B Daylight	12	MSRC	12 pm to 8 pm	6:45 am to 8:00 pm
Mini Barge B Night (AM)	12	MSRC		12:00 am to 6:45 am
Mini Barge B Night (PM)	12	MSRC	8 pm to 12 am	8 pm to 12 am
Mini Barge C Daylight	12	MSRC	12 pm to 8 pm	6:45 am to 8:00 pm
Mini Barge C Night (AM)	12	MSRC		12:00 am to 6:45 am
Mini Barge C Night (PM)	12	MSRC	8 pm to 12 am	8 pm to 12 am
Oregon Responder Daylight	10	MSRC	10 am to 8 pm	6:45 am to 8:00 pm
Oregon Responder Night (AN	10	MSRC		12:00 am to 6:45 am
Oregon Responder Night (PN	10	MSRC	8 pm to 12 am	8 pm to 12 am
Peregrine Daylight	7	MSRC	7 am to 8:00 pm	6:45 am to 8:00 pm
Peregrine Night (AM)	7	MSRC		12:00 am to 6:45 am
Peregrine Night (PM)	7	MSRC	8 pm to 12 am	8 pm to 12 am
Royal Tern Daylight	23	MSRC		6:45 am to 8:00 pm
Royal Tern Night (AM)	23	MSRC		12:00 am to 6:45 am
Royal Tern Night (PM)	23	MSRC	11pm to 12 am	8 pm to 12 am
Sandpiper Daylight	8	MSRC	8 am to 8:00 pm	6:45 am to 8:00 pm
Sandpiper Night (AM)	8	MSRC		12:00 am to 6:45 am
Sandpiper Night (PM)	8	MSRC	8 pm to 12 am	8 pm to 12 am
Shearwater Daylight	22	MSRC		6:45 am to 8:00 pm
Shearwater Night (AM)	22	MSRC		12:00 am to 6:45 am
Shearwater Night (PM)	22	MSRC	10 pm to 12	8 pm to 12 am
Speed Sweep R12 Daylight	12	NRC	12 pm to 8 pm	6:45 am to 8:00 pm
Speed Sweep R12 Night (AM	12	NRC		12:00 am to 6:45 am
Speed Sweep R12 Night (PM	12	NRC	8 pm to 12 am	8 pm to 12 am
Speed Sweep R7 Daylight	7	NRC	7 am to 8:00 pm	6:45 am to 8:00 pm
WC Park Responder Daylight	21	MSRC		6:45 am to 8:00 pm
WC Park Responder Night (A	21	MSRC		12:00 am to 6:45 am
WC Park Responder Night (PI	21	MSRC	9 pm to 12 am	8 pm to 12 am